THE UNIVERSITY OF ALBERTA

A PHOTOGEOLOGIC STUDY OF SELECTED GROUND MORAINE AREAS: SURFACE FEATURES AND THEIR SIGNIFICANCE

A THESIS

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ABSTRACT

The term 'ground moraine' was originally applied to till surfaces deposited under an active glacier; later workers extended this meaning to include till surfaces formed of ablation debris. Other variations in the application of this term, combined with the above mentioned alternative usages, have placed a limitation on the usefulness of this term as a label for gently rolling till surfaces.

A detailed photogeologic study of selected till surfaces mapped as ground moraine in central North America, Ontario and Alaska, indicates that one or the other of two main classes of surface features noted is predominant within a particular region: (1) streamlined surface features are distinctive on the surface studied in Ontario, are common in the Alaska study area and appear as several small patches of fluting on the surfaces studied in Alberta and Montana and (2), low hummocks, straight to circular ridges and depressions are common to the areas studied in central North America.

The till surfaces marked by streamlined forms are classified as 'ground moraine' and the more or less irregular till surfaces as 'ice-disintegration moraine'. Ice-disintegration moraine is considered to have formed primarily by ablation and by the squeezing-up of basal debris into cavities and crevasses in stagnant or near-stagnant ice. Some of the ice-disintegration features noted possess characteristics indicative of one or the other of these two modes of origin under generally stagnant ice conditions, therefore four secondary and six

tertiary sub-classes are included, involving morphological and genetic considerations.

These findings lead to the conclusion that stagnation was the mode of ice wastage over large parts of the continental interior, as has been suggested by other workers. Normal recession (more or less uniform retreat of the ice edge) within the areas studied appears to have been common only to the Ontario and Alaska areas.

ACKNOWLEDGEMENTS

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INTRODUCTION

A. Purpose of this study

1. Problem

Varied usage of the term 'ground moraine' has created problems related to the mapping of glacial deposits. The term has been applied mainly to two types of non-stratified drift: (1) till deposited at the base of an active glacier and (2), till deposited at the base of a glacier, from within and from the surface of a glacier, as the result of ablation (ablation moraine). Other minor variations in usage have caused additional confusion.

The term 'ground moraine' had its origin in the old Savoy word 'moraine' meaning loose, earthy material (Cook, 1945, p. 330). Martins in 1842 introduced the term 'moraine profonde' which was later translated into the German as 'Grundmoräne' and into the English as 'ground moraine' (Flint, 1955, p. 111). Agassiz labelled subglacial deposits of tough mud enclosing striated stones, ground moraine (Cook, ibid.). Flint (ibid.) states that the original term 'moraine', as used by Bohm in 1777 and de Saussure in 1786, had topographic implications which he feels are therefore inherent in the term 'ground moraine'.

The extended application of the term was first made when the supposed dual origin - glacial and marine - of certain deposits was disproved and Swedish geologists included the upper layer, formerly called 'diluvium', along with the basal till as ground moraine (Cook, 1945, p. 331-332). Cook (ibid.) states that the

Swedish usage was introduced to America in 1876 by Torell, but this is not evident from Torell's (1877, p. 77) definition "... while another portion was passed over by the ice and then became bottom or ground moraines."

Chamberlain (1894, p. 517-538) proposed a classification of glacial deposits in which the term 'ground moraine' was used in much the same way as Agassiz used it. One of six general classes in his "Proposed Genetic Classification of Pleistocene Glacial Formations" was "Formations produced by the direct action of Pleistocene glaciers". The following sub-headings were placed under this class:

A. Formations that are gathered at the bottom of glaciers.

  (1) Subglacial sheets of till ("one form of ground moraines")

  (2) Subglacial aggregations of till

    a. Drumlins

    b. Aggregations of till not strictly drumloid in form

B. Formations derived from material borne on the glaciers and within them (but not at their basal contact) and deposited at their margins, or let down directly by their melting when stagnant.

  (1) Dump moraines

  (2) Englacial or superglacial till (upper till)

  (3) Medial moraines (p. 520-528)

Salisbury's (1908, p. 257) definition, "the drift deposited by the ice but not aggregated into thick belts at its edge is ground

moraine", indicated a trend back to the old Swedish usage, as did Thwaites' (1937, p. 40) classification, in which he subdivided ground moraine into: (1) areas of thin moraine whose topography is controlled by bedrock; (2) drift plains (till plains); (3) miscellaneous, gently rolling, flat drift that cannot be classified as anything else. Drumlins are not included as a part of ground moraine. However, MacClintock and Apfel (1944, p. 1158) included small kames and kame fields of limited extent as a part of ground moraine.

Under the heading of "Ground moraine", Deane (1950, p. 11) excludes terminal moraines and drumlins but includes all other drift that has not been re-worked by water.

Flint (1955, p. 111-112) points out that Salisbury's definition of 1908 is inadequate, as it doesn't require that the deposit have a constructional topography of its own and proposes that "ground moraine can be thought of as moraine of low relief devoid of transverse linear elements". He adds that "Much ground moraine is the result of rubbing off or lodgment upon the ground, of drift contained at the base of flowing ice. Some ground moraine, however, includes drift let down, from the upper surface of thin stagnant ice, on to the ground in consequence of ablation of the ice". Only when a till surface possesses constructional irregularities does Flint consider it to be ground moraine; a till surface lacking such irregularities is not considered to be moraine but "ablation drift" and "part of a till sheet" because the till is thin and does not have a topography of its own. Surface form and topography are considered essential criteria in Flint's definition of ground moraine.

Christiansen (1956, p. 9), in describing ground moraine within a mapped area, states that "the ground moraine comprises an area of low relief consisting predominantly of till modified locally by such features as drumlins, fluting, minor recessional ridges, crevasse fillings, eskers and kames. This land form is often referred to as a till plain ...".

Current European usage is fairly well represented in the literature of Woldstedt (1954, p. 28-29), Charlesworth (1957, p. 376-385) and Zeuner (1959, p. 23).

Woldstedt (ibid.) believes that confining the term to subglacial till as proposed by the International Glacier Commission of 1899 is impractical. He points out that gradations from till separated by ice layers to ice layers separated by till have been observed in recent glaciers thus making the separation of subglacial from englacial till impossible. Under the heading of "ground moraine" Woldstedt (1954, p. 90-100) includes the following sub-headings: (1) ablation forms of ground moraine, i.e., ground moraine plains (Grundmoränenebene); (2) Hummocky ground moraine (Kuppege Grundmoränenlandschaft); (3) drumlins.

Charlesworth (1957, p. 380-385) also indicates the difficulty of distinguishing between till of subglacial origin and that of englacial origin. Each of these two types of till may form till plains, which he states "... may owe their existence to the thickness of the drift, to deposition by dead ice, to the slow uniform rate of retreat, or to later periglacial effects" (p. 385). He discusses till plains under the chapter heading of "Boulder Clay" - the latter term is also

used synonymously with the term 'ground moraine' (p. 379).

Ground moraine is called 'bottom moraine' by Zeuner (1959, p. 23) who also includes the material thawed out of the ice, though he does add that "... englacial moraine would be a more correct expression" for this thawed-out material.

Because of these disparate usages and the confusion they engender, some recent European and American publications make little or no use of the term. Hoppe (1952, p. 7-14; 1957, p. 1-9) makes no mention of ground moraine in descriptions of hummocky moraine areas and washboard moraines in Sweden. No reference to ground moraine is made by Witkind (1959, p. 16-18) who applies the term 'till sheets' to surficial deposits of till in Montana. Smith, Witkind and Trimble (1959) use the term only twice; in discussing a formation composed of till they state "most of the area gives an impression of gently rolling ground moraine" (p. 137), and under the heading "Superglacial Till" they speak of "... the gently rolling ground moraine formed on the Lothair till" (p. 138).

2. Approach

This study is intended to determine whether selected areas in North America mapped as, or indicated by some geologists to be, ground moraine, have features exhibiting forms and patterns that indicate the mode of origin of the surfaces in these selected areas, such that these areas may be more rigorously classified. Stereoscopic study of aerial photographs is an excellent method of detecting small features, and particularly patterns of features, many of which may not be apparent to an observer on the ground.

a. Materials used

Vertical aerial photographs on a scale of from one inch to 1320 feet to one inch to one mile were used. Topographic map coverage was available for most of the areas studied and photo mosaics were available for a few of these areas. Surficial geology maps were used in close conjunction with the air photos.

High and low pocket steroscopes were used as well as an Old Delft scanning stereoscope and an Academy height finder Model HF-2 (Abrams). Measurements were made with standard small division photo-interpretation equipment.

b. Procedure

Photos covering the study areas were examined stereoscopically and the general nature of the surface was described. Detailed measurements were then made of the length, width, height and orientation (where applicable) of surface features. Plan measurements were made using a tube magnifier or scale, and readings were converted to true distances by calculation. Readings obtained by means of the height finder, which attaches to the four-inch pocket stereoscope, were converted to actual relief by means of a calculated conversion factor dependent upon the stereoscopic print base and the flight altitude. A protractor was used to determine the orientation of linear ridges and depressions after the photos were map-oriented.

Data on features within one or two sections covered by each stereo-pair were tabulated, along with other information concerning each area, under the headings of location, photo number, type of feature,

orientation, dimensions, shape and other aspects. A general description of the area covered by each stereo-pair accompanied the data sheet as well as an acetate tracing of features or patterns of features in some of these areas; these tracings appear in various figures in the text. Field checks of a reconnaissance nature were made in several areas and one feature was mapped in detail by plane table and alidade.

A glossary is included in order to clarify terminology in instances where a term has several definitions or where uncommon or new terminology is used.

c. Errors involved in measurements

The errors involved in the above measurements depend upon several factors, the most important being the scale of the photos and operator error. Operator error must be considered in the measurement of heights, and wherever possible height measurements were checked against topographic maps, inasmuch as readings obtained with the height finder are subjective.

The following table gives estimates of probable errors in measurement. The margin of error involved in measurement of orientation is not significant as the rose diagrams are plotted by ten-degree intervals.

Scale of photos	Probable errors in plan measurements	Probable errors in height measurements
1" to 1320'-1" to 1760'	20'±	2.5'±
1" to 3333'	40'±	5.0'±
1" to one mile	60'±	5.0'±

Dimensions of most of the features described are given in terms of length, width, height and depth. The dimensions of most depressions are given only in terms of length and depth, where the length is the distance measured along the major axis.

d. Selected study areas

Drift surfaces mapped or labelled as ground moraine are described within the following areas (Fig. 1):

(a) Moose Mountain area, Saskatchewan between latitudes 49° 30' and 49° 50' N., longitudes 102° 45' and 103° 30' W.

(b) Carpio and Tolley areas, North Dakota between latitudes 48° 15' and 48° 45' N., longitudes 101° 30' and 102° W.

(c) Jamestown area, North Dakota between latitudes 46° 52' and 47° N., longitudes 98° 30' and 98° 51' W.

(d) Tipton, Decatur and Shelby Counties, Indiana and Champaign County, Illinois between latitudes 39° 15' and 40° 30' N., longitudes 85° 15' and 88° 30' W.

(e) West Butte and Kevin areas, Toole County, Montana between latitudes 48° 45' and 48° 50' N., longitudes 111° 30' and 111° 55' W.

(f) Sedgewick and Coronation areas, Alberta between latitudes 52° 15' and 53° N., longitudes 111° 15' and 112° W.

(g) Ste. Anne area, Alberta between latitudes 53° 44' and 53° 48' N., and longitudes 114° 45' and 114° 51' W.

(h) Lindsay-Peterborough area, Ontario between latitudes 44° and 44° 20' N., longitudes 78° and 78° 30' W.

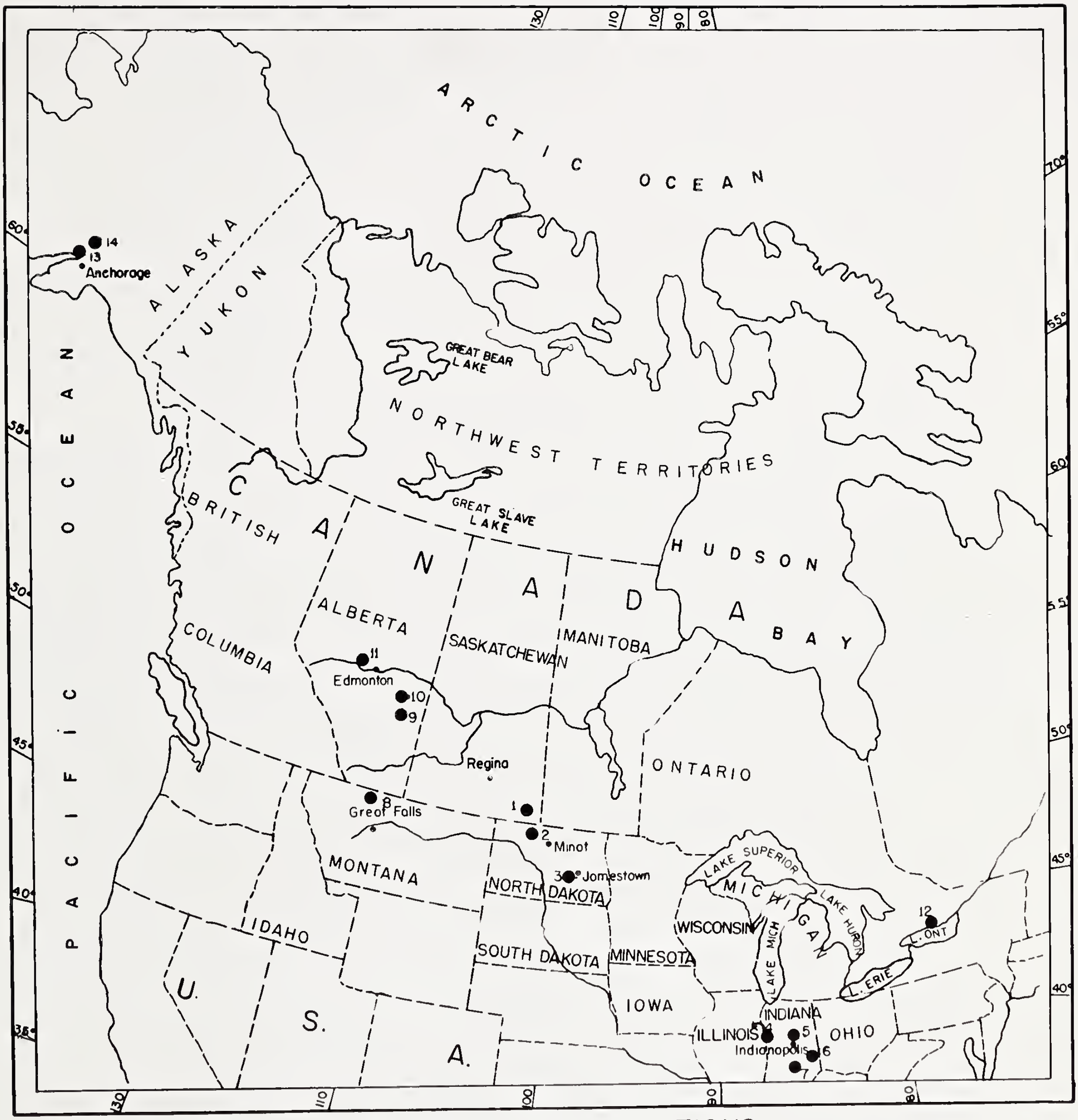


FIGURE 1. INDEX MAP OF STUDY AREA LOCATIONS

1. Moose Mountain
2. Corpio—Talley
3. Jamestown
4. Chompaign.
5. Tipton
6. Shelby
7. Decotur
8. West Butte Kevin
9. Coronation
10. Sedgewick
11. St. Ann
12. Lindsoy—Peterborough
13. Tyonek
14. Talkeetno

SCALE
0 250 500
Miles

(i) Tyonek and Talkeetna areas, Alaska between latitudes 61° and 62° 30' N., longitudes 150° 30' and 151° 30' W.

B. Previous work

Isolated features or groups of features that appear on drift surfaces mapped as ground moraine have been described by many workers. Most publications concerning the surficial geology of glaciated areas include a discussion of the general nature of areas referred to as 'ground moraine'.

Since air photos began to be used extensively in mapping surface deposits, many of the minor land forms appearing on these 'ground moraine' surfaces have been described in detail. Flint (1928, p. 414) applied the term 'crevasse filling' to ridges of sand and gravel in the vicinity of recessional moraines and outwash plains; similar features formed on till surfaces were called 'ice-crack moraine' (Sproule, 1936, p. 104) and 'ice-block ridges' (Deane, 1950, p. 14). More recent descriptions of the same features again use the older term 'crevasse filling' or 'till crevasse filling' (Gravenor, 1956, p. 10-11; Kupsch, 1956, p. 1-5). Prairie mounds, common to much of the drift surface in western Canada have been described by Gravenor (1955, p. 475-481). Stalker (1960, p. 9-11) describes similar features in Alberta and labels them 'plains plateaux'. Parallel ridge patterns referred to as 'annual frontal moraines' by de Geer in 1897 (Hoppe, 1957, p. 1) were called 'washboard moraines' by Mawdsley (1936, p. 9-12), who described similar forms in Quebec. Gwynne (1942, p. 200) termed a series of such successive parallel ridges in Iowa 'swells and swales', and Elson (1957, p. 172)

again applied the term 'washboard moraine' to similar features in Manitoba, as did Hoppe (1957, p. 1-7) to forms in Sweden. The literature on glacial landforms abounds in descriptions of streamlined drift forms such as drumlins and fluting.

DESCRIPTIONS OF STUDY AREAS

A. Moose Mountain area, Saskatchewan

The Moose Mountain area lies in the southeast corner of Saskatchewan, approximately 30 miles north of the International Boundary between latitudes 49° 30' and 49° 50' N., and longitudes 102° 45' and 103° 30' W. (Fig. 1). All locations given are west of the second meridian.

Royal Canadian Air Force vertical air photos on a scale of one inch to 1400 feet, covering an area of approximately 400 square miles, were made available through Dr. W.O. Kupsch of the University of Saskatchewan. A map by Christiansen (1956) was used to delimit areas mapped as ground moraine. Field checks were made in several localities to verify data obtained from the air photos.

Glacial deposits of late Wisconsin age (Stockwell, 1957, p. 482) form the surface materials throughout the area, including the two preglacial highs of Moose Mountain and the Missouri Coteau, which border the study area. Moose Mountain, 15 miles northeast of the study area, and the Missouri Coteau, southwest of the same area, have elevations 500 feet and 400 feet, respectively, above the level of the drift plain. The orientation of fluting and washboard ridges in parts of the region indicate a northwest to southeast direction of ice movement (Christiansen, 1956, map).

Nature of the Surface

Shallow depressions, hummocks with light-colored tops and disintegration ridges of various sizes and shapes characterize the

gently irregular drift surface (Plate IA). Relief within the area averages about six feet; some localities have relief on the order of five feet while in other localities it may exceed 15 feet.

Small, low hummocks with white tops give much of the surface a speckled appearance. Somewhat larger hummocks are aligned to form white-crested, closed or linear disintegration ridges. The random orientation of such ridges, in areas where they are numerous, results in waffle-iron patterns and where a series of ridges have parallel trends, they produce 'washboard ridges'. Depressions are, as a rule, sharply outlined and appear in a variety of shapes and sizes. Minor linear depressions, U-shaped in cross-section, lying at or somewhat above the bottoms of larger, non-linear depressions, form a rather indistinct network between some of the larger depressions. Small meltwater channels are numerous in places on the drift surface and the larger channels show evidence of recent water erosion.

Drainage Pattern

Drainage is deranged in most parts of the area. Where glacial meltwater channels are numerous, modern drainage is confined to these old channel courses.

Surface Features

Hummocks -

Small hummocks 15 to 30 feet in diameter and one to two feet in height, impart a speckled appearance to the surface of, and areas between, larger features.

More distinct forms of hummocks are from 150 to 500 feet in

Explanation Plate I - Moose Mountain Area

A - Photo numbers - R.C.A.F. A11982-95,96; scale: 1" to 1400'.

Location: section 36, township 8, range 10, W. 2nd.

A typical disintegration moraine surface marked by depressions, hummocks, and subdued outlines of linear and closed disintegration ridges.

B - Photo numbers - R.C.A.F. A11982-92,93; scale: 1" to 1400'.

Location: parts of sections 32 and 33, township 8, range 9, W. 2nd.

Features in this area show a gradation from randomly oriented ridges into aligned ridges that result in 'wash-board ridge' patterns.

A.

B.

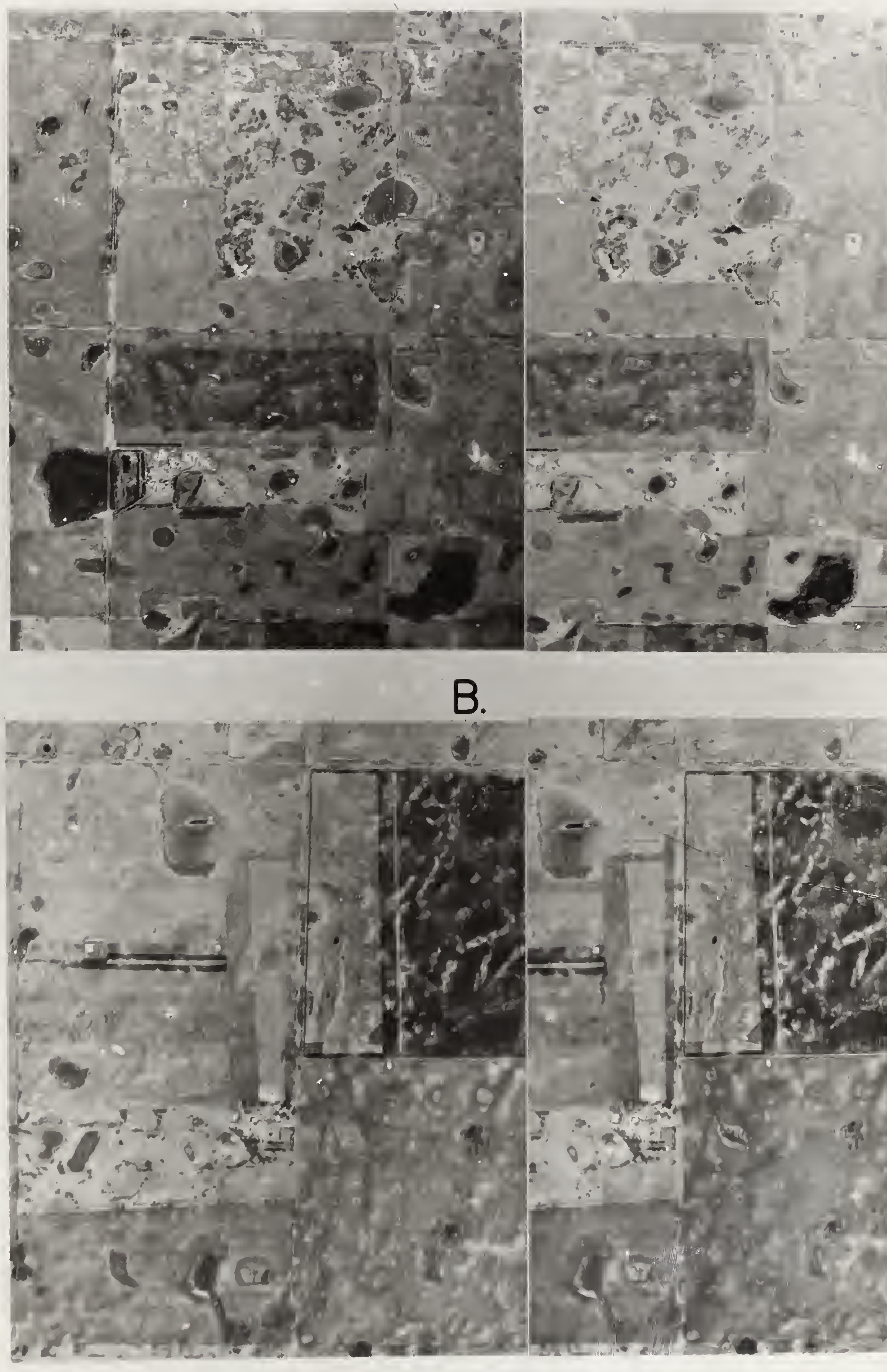


PLATE I

diameter and are 5 to 10 feet in height. They occur as isolated forms scattered on higher surfaces, or along the margins of depressions; local clusters of hummocks appear as white-dappled surfaces; closely spaced and aligned hummocks may grade into linear or closed disintegration ridges with irregular crests. The larger forms in this group of features are more common in the vicinity of meltwater channels and appear to be associated with closed disintegration ridges circular to oval in plan view. The surfaces of the largest forms are often pitted and usually lack the white top so common to the smaller hummocks of this size range.

Linear Disintegration Ridges -

These features are usually 150 to 250 feet in width and from 5 to 10 feet in height. Lengths are from 200 to 6000 feet but rarely exceed 2200 feet (Fig. 7B).

Forms straight and arcuate in plan with white mottled crests are most common but variations of form, hook-shaped to S-shaped in plan are also present. Outlines of the disintegration ridges are often subdued, except in the vicinity of large meltwater channels or in areas gradational into end moraines where distinct white crests mark the ridges (Plate IB).

Linear ridges that appear to be crevasse fillings occur in sections 10, 11 and 13, township 10, range 7 (Photos A11992-149, 1503; Plate IIA). These ridges are 200 to 1700 feet long, 30 to 80 feet wide and less than five feet high. They are very straight with even-colored crests and have a maximum variation in the orientation of their long axes of about 10 degrees. One form about 600 feet long is

Explanation Plate II - Moose Mountain area

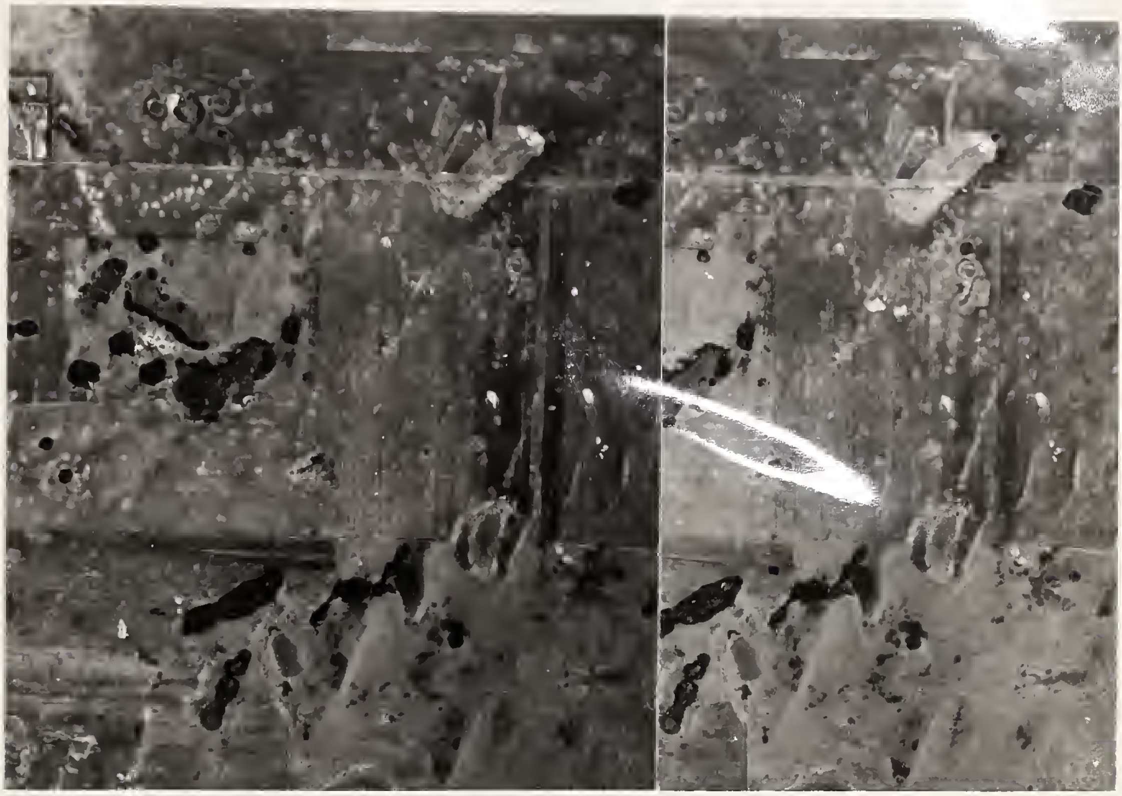
A - Photo numbers - R.X.A.F. A11992-149,150; scale: 1" to 1400'. Location: parts of sections 10 and 13, township 10, range 7, W. 2nd.

The prominent ridges in this area are crevasse fillings. Note the crevasse fillings superimposed upon the closed disintegration ridge in the upper right-hand corner.

B - Photo numbers - R.C.A.F. A11983-173,174; scale: 1" to 1400'. Location: parts of sections 2 and 11, township 7, range 9, W.2nd.

Highly subdued outlines of linear and closed disintegration ridges appear in the lower half of the area (Fig. 2C).

A.



B.

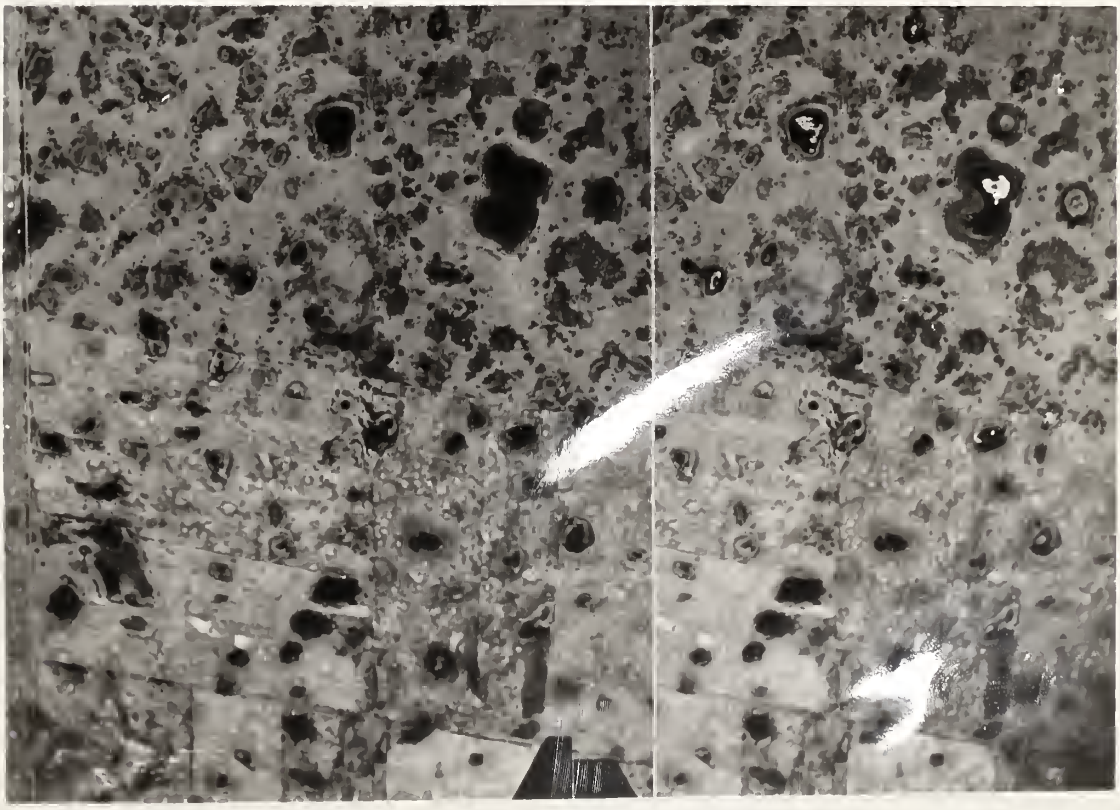


PLATE II.

S-shaped in plan view. Spacing between these ridges is from 350 to 1000 feet but most of them are less than 500 feet apart. In the northeast quarter of section 10 and the southeast quarter of section 13, two crevasse fillings appear to be superimposed upon a large closed disintegration ridge. The closed disintegration ridge 350 feet wide and 22 feet high (measured from the ridge crest to adjacent outer surface) encloses a flat area that is 1000 feet long, 550 feet wide and appears to be somewhat lower than the surface outside the ridge. The crevasse fillings are 300 to 400 feet long, 50 feet wide and about five feet high. The shorter feature lies along the crest of the closed ridge and the longer one extends from the crest, part way across the bottom of the depression. Both crevasse fillings are oriented in about the same direction across the closed ridge, which is roughly triangular in plan. A field check indicated that crevasse fillings in this area are composed of stony till.

In section 20, township 10, range 7, (Photos A12006-39,40) a strip of mapped ground moraine about four miles wide contains several mile-long disintegration ridges. The strip lies between an outwash plain and dead-ice moraine. These ridges roughly parallel similar but shorter segments associated with them. One of the ridges, 5000 feet long, 100 feet wide and five feet high, is essentially straight with slight arcs in places. Another form consists of several more markedly arcuate segments, resulting in a single ridge 6000 feet long, 80 feet wide and five feet high. Spacing between the long and short segments is from 250 to 500 feet and the continuity of a single ridge

Explanation Plate III - Moose Mountain area

A - Ground view looking northwest, of several crevasse fillings marked by an 'X' in Plate IIA. These features were noted to be composed of very stony till.

B - Ground view across the crest of a closed ridge in the area marked by an 'X' in Plate IIB. Note the stony nature of the surface.

may be broken by an offset of about 100 feet. The typical white-mottled crest is absent from the long ridges and most of the shorter segments, but it appears where these ridges grade into adjacent deposits lacking apparent parallel trends. Even-toned, light-colored crests mark most of the ridges in this section. Depressions among the ridges have light-colored bottoms as well, making them less apparent than the dark-bottomed depressions common to other areas.

Closed Disintegration Ridges -

An association of hummocks, closed disintegration ridges and depressions in section 2, township 7, range 9 (Photos A11983-173,174, Plate IIB and Fig. 2C) is quite subdued in outline. A depression less than five feet in depth and 80 feet in diameter, is enclosed by a ridge, circular in plan, forming a feature 450 feet in diameter. The surface between the outer margin of the depression and the inner base of the ridge, appears flat. Next to the above feature is a closed ridge 250 feet wide, five feet high and 800 feet in diameter, enclosing a constructional depression, the bottom of which lies at about the same level as the surface outside the ridge (Fig. 3A). Another form appears as a prairie mound, 450 feet in diameter and about five feet high, which appears to have its surface marked by a shallow depression off to one side.

The northeast quarter of section 2, containing the above described features, was examined on the ground; low rises mark the presence of ridges of relief from three to six feet; shallow depressions are also evident but none of the patterns apparent on the air photos can be discerned (Plate IIIB).

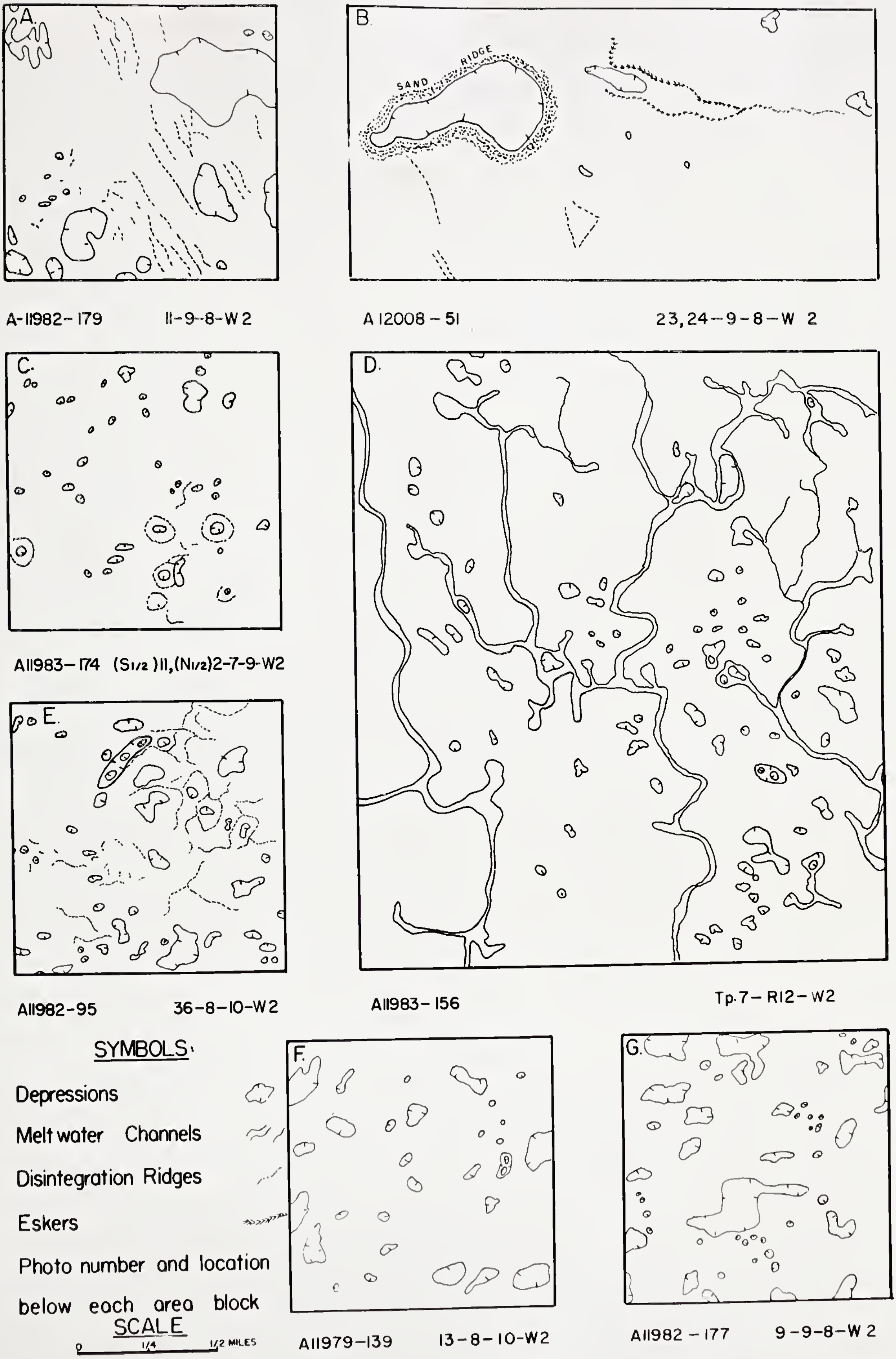


FIGURE 2 - PATTERNED SURFACE FORMS WITHIN AREAS MAPPED AS "GROUND MORAINE" — MOOSE MOUNTAIN AREA.

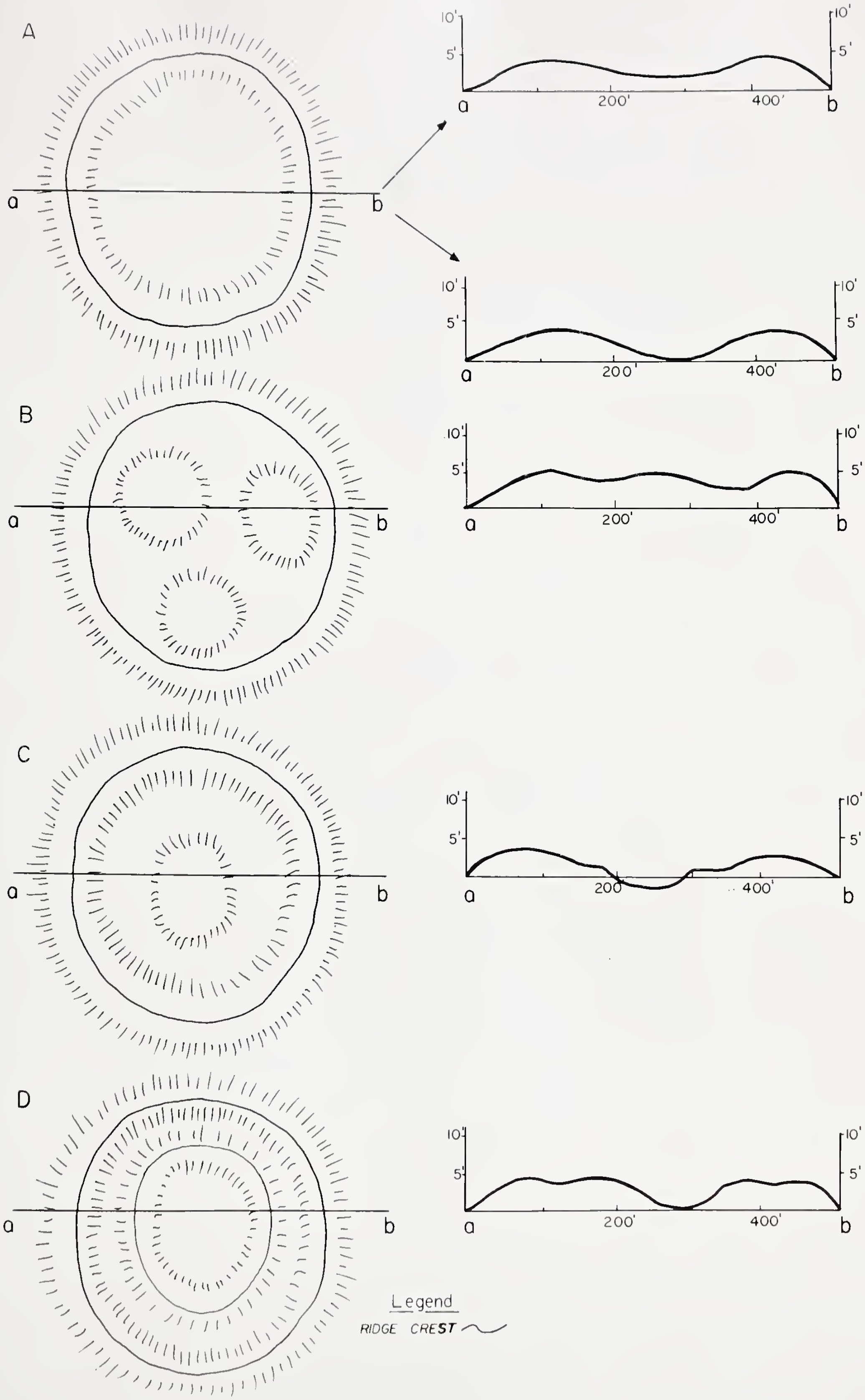


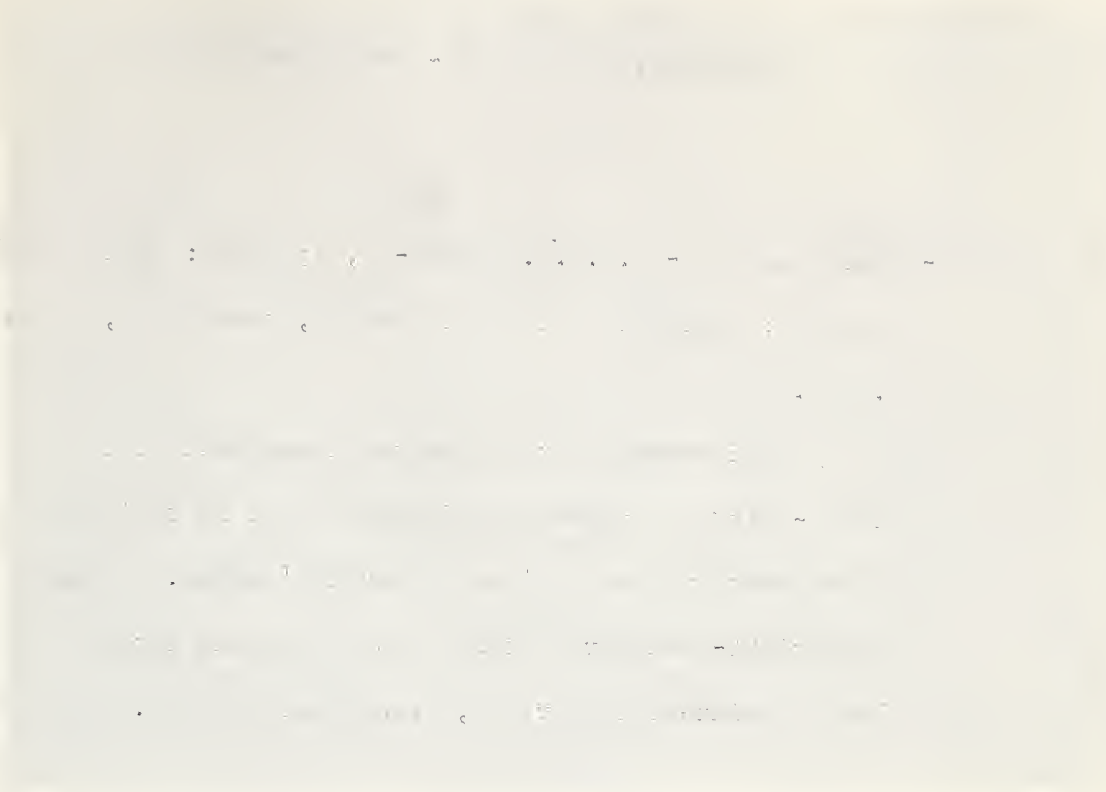
FIGURE 3 SKETCHES OF PLAN VIEWS AND PROFILES OF TYPICAL CLOSED DISINTEGRATION RIDGES OF AVERAGE DIMENSIONS

Sections 12 and 13, township 7, range 11 (Photos A11991-64, 65) contain forms similar to those described above. A rounded hummock 500 feet in diameter and about five feet high, occurs close to a closed ridge, oval-shaped in plan view, 500 feet long, 200 feet side and five feet high. Two rimmed kettles about 600 feet in diameter have rims 150 feet wide and five feet high, enclosing the kettles (Fig. 3C). Two prairie mounds are also present in this area; the larger form has dimensions of length and height of the same order as the above described features; the smaller feature is 250 feet in diameter and about five feet high.

Several closed ridges occur in section 23, township 9, range 8 (Photos A12008-51,52). Three till ridges (Plate IVA and Fig. 2B), in the southeast quarter of the same section, are joined to form a closed disintegration ridge in the form of an isosceles triangle, with two sides 700 feet long and one side 800 feet long. The ridge is 250 feet wide and 10 to 15 feet high. A study of this feature in the field showed that it is composed of stony till, and its outline is readily discerned on the ground. Another closed ridge, 40 feet wide and three to eight feet high, enclosing a large depression 3600 feet long is not a disintegration ridge as it is composed of fine sand and silt and its origin appears to be related to former wind activity in this area (Fig. 2B).

Washboard Ridges -

In sections 23, 26 and 35, township 8, range 8 (Photos A11979-219,220), in a contact area between deposits mapped as ground moraine and end moraine, arcuate to straight disintegration ridges

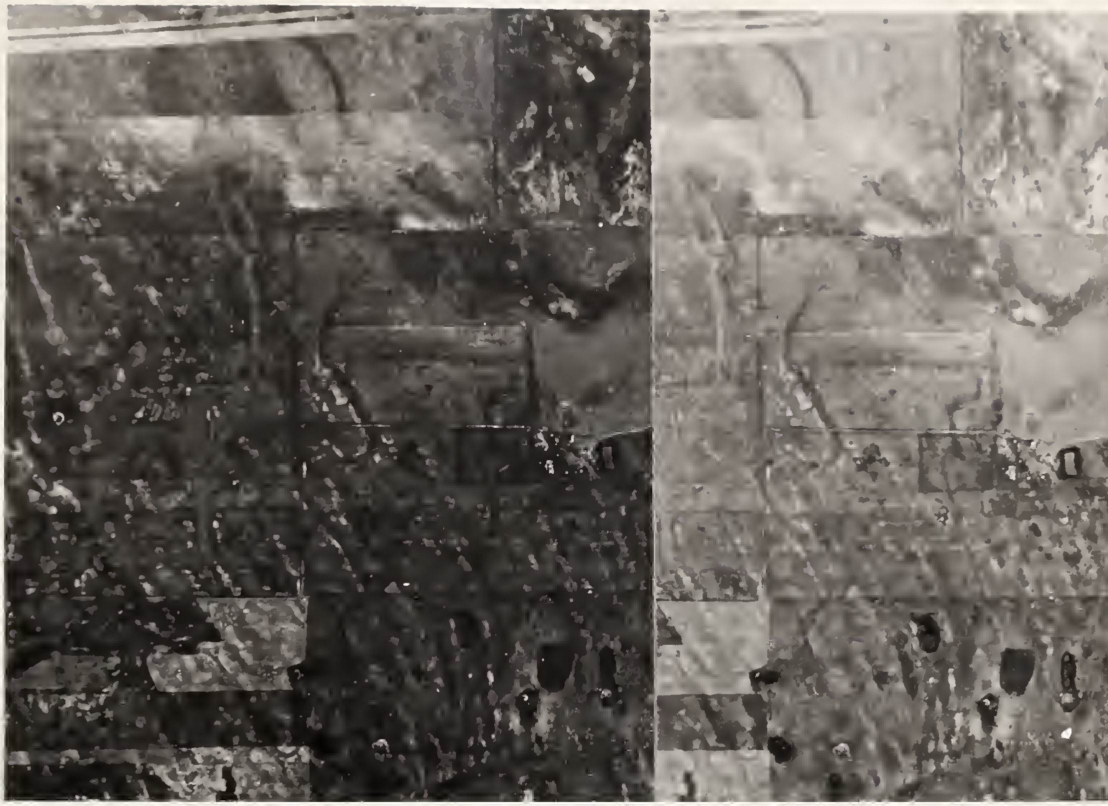


Explanation Plate IV - Moose Mountain area

A - Photo numbers - R.C.A.F. A12008-51,52; scale: 1" to 1400'.
Location: parts of sections 14 and 23, township 9, range 8, W. 2nd.
The type of washboard ridge in the lower half of the stereo-pair was mapped as end moraine but is typical of washboard ridges in 'ground moraine' areas. In the upper right-hand corner three ridge segments form a closed disintegration ridge, triangular in plan.

B - Photo numbers - R.C.A.F. 11983-171,172; scale: 1" to 1400'.
Location: section 9, township 7, range 9, W. 2nd.
This area contains several larger forms of meltwater channels. The steep sides of the depressions in this area indicate that they were probably formed by ice blocks and can therefore be called 'kettles'.

A.



B.

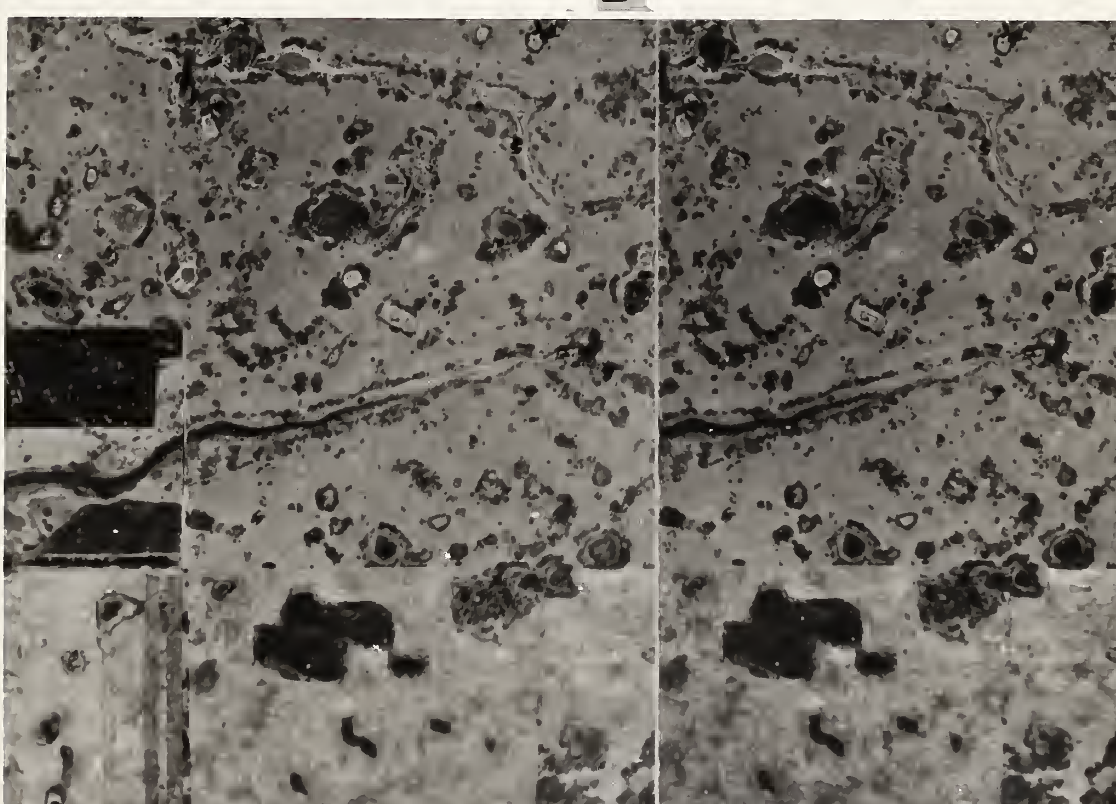


PLATE IV.

about 100 feet wide and 5 to 10 feet high, appear to be made up of closely spaced hummocks. Isolated hummocks, identical to those making up the ridges, lie scattered between the ridge forms. Sometimes the ridges are U-shaped in plan view, forming arcs around depressions. The overall pattern of the parallel ridge trends formed by these features shows up very sharply because of the white-mottled ridge crests. Re-entrants of 'ground moraine' lacking linear trends, separate these broadly lobate tongues formed by the washboard ridges. Similar washboard ridge patterns occur in the vicinity of large meltwater channels as previously mentioned in the section under linear ridges.

Section 14, township 8, range 9 (Photos A11979-133,134), contains similar ridges exhibiting parallel trends. Randomly-oriented ridges, low hummocks and depressions are also present. No marked trends were evident when examined on the ground; only an irregular surface characterized by hummocks and ridges with a relief of 5 to 15 feet was apparent in a field check of this section.

Eskers -

An esker-like ridge appears within a re-entrant of 'ground moraine' into end moraine, and crosses the north half of section 23, township 9, range 8 (photos A12008-52,53). It is continuous for a distance of about one mile, with a sinuous east-west trend approximately at right angles to the washboard ridges in the area. The esker is 5 to 10 feet high, 80 feet wide and has an even-toned, light grey surface on the air photos. The branches of this feature, in the northwest

quarter of section 23, are composed of a series of short till ridges and no trend is noticeable to an observer on the ground. However, the main portion is clearly outlined, and was identified in the field as a ridge with an irregular crest (Fig. 2B).

Depressions -

Depressions are the most obvious features on the drift surface and occur with a marked frequency, averaging 25 per square mile. Some open forms lie at the heads of meltwater channels or appear to be constructional features.

The depressions occur in a wide range of sizes, from mere pits on the surface to the rare forms several miles in length (Fig. 7D).

Outlines of the depressions are rounded, rectangular, oval and irregular and occur in a ratio of 1:3:5:5. Sides of the depressions are, as a rule, smoothly rounded and often merge into, or appear to be formed by, hummocks and ridge segments. Steep-sided forms are rare; several of these do appear in an area bounded by two large meltwater channels in section 9, township 7, range 9 (Photos A11983-171,172; Plate IVB). Ridges are not distinct within this area and the surface is unusually irregular.

Bottoms of the depressions are usually flat to slightly concave and appear darker than adjacent elevated surfaces. Trees frequently outline the periphery of the bottoms and in the case of small depressions, may completely cover it. Cultivation may extend to the bottoms of depressions and the large, dry forms have bottoms smooth enough to permit the harvesting of hay. Absence of the dark bottoms and the lack of trees within some of the depressions is probably

related to moisture content and composition of materials, as well as to agricultural activity.

Although depressions rarely exhibit marked erosional effects, exceptions do occur in areas having a high incidence of meltwater channels.

Meltwater Channels -

Several large meltwater channels originate within the study area and local networks are formed by small channels. Numerous meltwater channels cut through section 12, township 7, range 12 (Photos A11983-156,157; Fig. 2D). The channels are 5 to 10 feet deep and 20 to 300 feet wide. Some of the narrow forms may have fairly steep sides and broader forms may have U-shaped cross sections or steep walls; small depressions may also appear on the bottoms of larger forms. Some channels originate in open depressions and form a continuous network between successive depressions. Within the east-half of section 12, a meltwater channel appears to have had several sections of a former course blocked by drift.

A portion of a large meltwater channel system within the study area crosses sections 8 and 9, township 7, range 9 (Photos A11983-171,172; Plate IVB). The channel is 50 to 200 feet wide, 10 feet deep and lies in a valley 800 feet wide and 30 feet deep, whose sides slope gently towards the channel. Where the valley widens, open depressions may lie next to the meltwater channel.

Two small alluvial fans were noted lying at the bottom of a meltwater channel 700 feet wide and 20 feet deep, crossing section 2,

township 8, range 9 (Photos A11991-212,213). The larger alluvial fan is about 700 feet long, 500 feet wide and five feet high and appears to have been formed by a stream that occupied a small channel that shows up quite well where it enters the main channel.

B. Carpio and Tolley areas, North Dakota

The Carpio and Tolley areas lie in the northwestern part of North Dakota in the vicinity of the Des Lacs and Souris rivers. The Carpio area, between latitudes 48° 15' and 48° 30' N. and longitudes 101° 30' and 101° 45' W., lies just above the junction of the rivers. The Tolley area, between latitudes 48° 30' and 48° 45' N. and longitudes 101° 45' and 102° W., lies within a belt 25 miles wide between the rivers, approximately 20 miles northwest of the junction (Fig. 1).

Vertical air photos with scales of one inch to 1760 feet and one inch to 2400 feet, of an area of approximately 80 square miles, were made available for study through Mr. R.W. Lemke of the United States Geological Survey. Topographic maps on a scale of 2.6 inches to the mile and contoured at five-foot intervals, as well as a preliminary map of the surface geology of the Carpio Quadrangle (Lemke, 1947b) were used. Several localities in the Carpio area were checked in the field and one feature was mapped with a plane table and alidade on a scale of one inch to 50 feet.

The last ice advance took place during late Wisconsin time, in a northeast to southwest direction in the Tolley area; till thickness is generally 75 to 100 feet (Lemke, 1947a, p. 7,10).

Nature of the Surface

Local relief in the area is from 5 to 15 feet, with the gently undulating surface common to localities having a relief on the order of five feet. Surface forms and patterns differ little from those described in the Moose Mountain area. Apparent parallel trends are lacking; randomly-oriented ridges and hummocks with white-colored tops are common surface forms. Prairie mounds are very common and the surfaces of these features often have a finely speckled appearance. Depressions occurring in these areas are often indistinct and most of them are less than 500 feet long. A few meltwater channels occur as extensions of broad, steep-sided gulleys which usually lie at right angles to the spillways in which they now terminate.

Drainage Pattern

No integrated drainage pattern is evident on the drift surface except in the immediate vicinity of large spillways in this area. Along the margins of two spillways, now occupied by the Des Lacs and Souris rivers, deeply incised gulleys lie at right angles to the trend of the spillway valleys and extend for distances of one to two miles into adjacent drift surfaces.

Surface Features

Hummocks -

These forms are common features, 80 to 600 feet long, from about 3 to 10 feet high and circular to oval in plan view. They appear to be gradational into prairie mounds, as they are often

associated with them. Such an association of features is apparent in section 3, township 156 N., range 86 W. (Photos BAM-64R-79,80; Plate VA; Fig. 4E).

Linear Disintegration Ridges -

Most of the ridges in this area are arcuate to sinuous in plan; straight forms are not as common. The ridges are from 250 to several thousand feet in length, 80 to 250 feet wide and about 3 to 10 feet high.

In section 29, township 157 N., range 84 W. (Photos GS-CD-365,366; Fig. 4A), ridges arcuate to sinuous in plan occur in the vicinity of an esker complex. One sinuous ridge, 900 feet long, 170 feet wide and about 10 feet high, curves around a depression. Similar forms appear in section 7, township 159 N., range 86 W. (Photos BAJ-17-10,11; Fig. 4D). A hook-shaped form 2000 feet in length along the straight portion, 80 feet wide and about five feet high, partly encloses a depression 200 feet long and less than five feet deep.

Closed Disintegration Ridges -

Closed disintegration ridges such as prairie mounds and rimmed kettles are very common in this area and are frequently associated with hummocks.

Section 29, township 157 N., range 85 W. (Photos GS-CD-368, 369; Fig. 4F) contains a variety of closed ridges. One of these forms in the southwest quarter of the section has coiled outline in plan view. The ridge proper is 100 to 200 feet wide about five feet high and closes to form a feature about 1000 feet in diameter. This

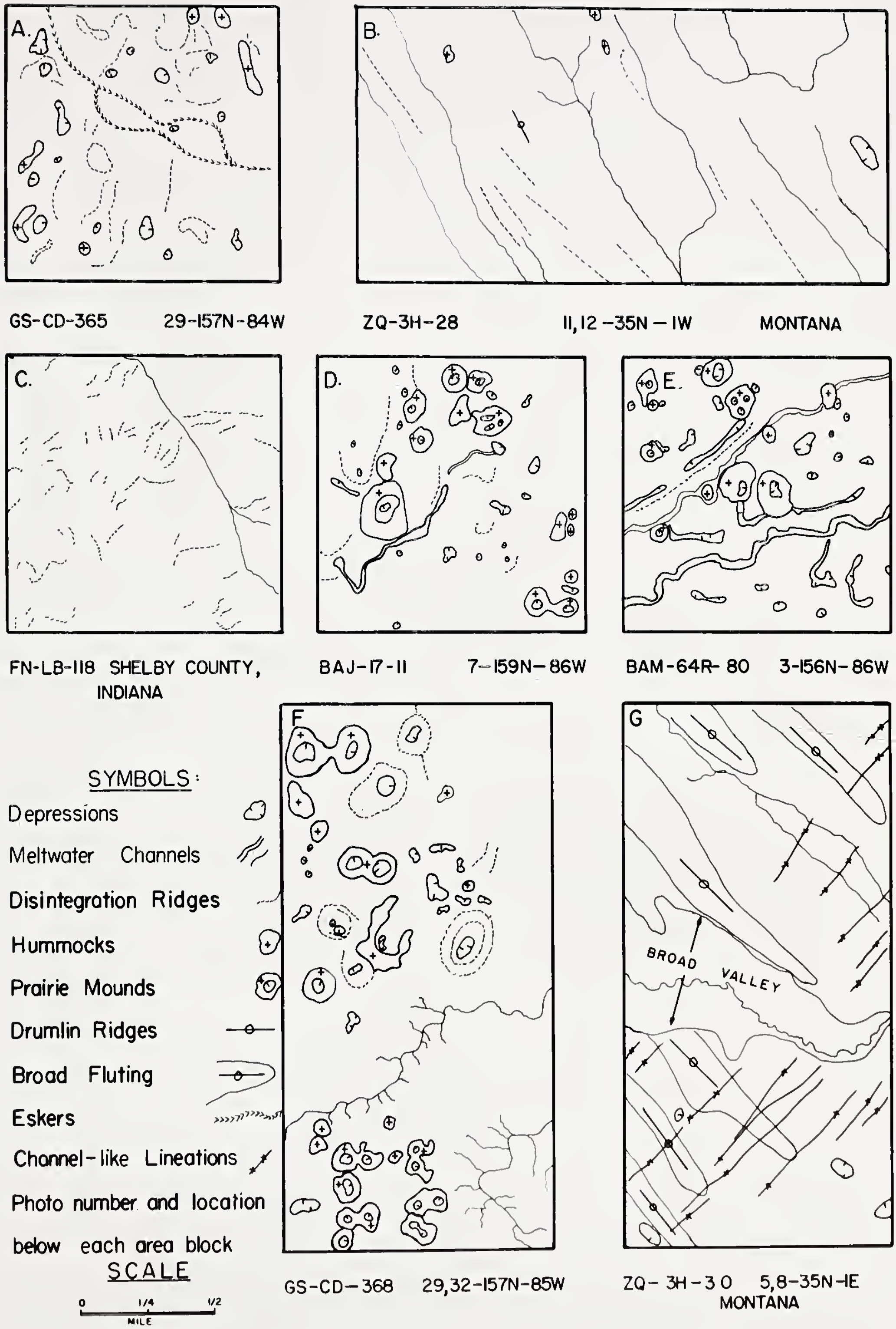


FIGURE 4. — PATTERNED SURFACE FORMS WITHIN AREAS MAPPED AS "GROUND MORAINE" IN NORTH DAKOTA, ALSO MONTANA AND INDIANA WHERE SO LABELLED.

Explanation Plate V - Carpio area

A - Photo numbers BAM-64R-79,80; scale 1" to 2400'; Location: section 3, township 156 N., range 86 W. Meltwater channels are prominent within this area and prairie mounds appear to be superimposed upon the channels (Fig. 4E).

B - Ground view of the closed disintegration ridge illustrated in Figure 5.

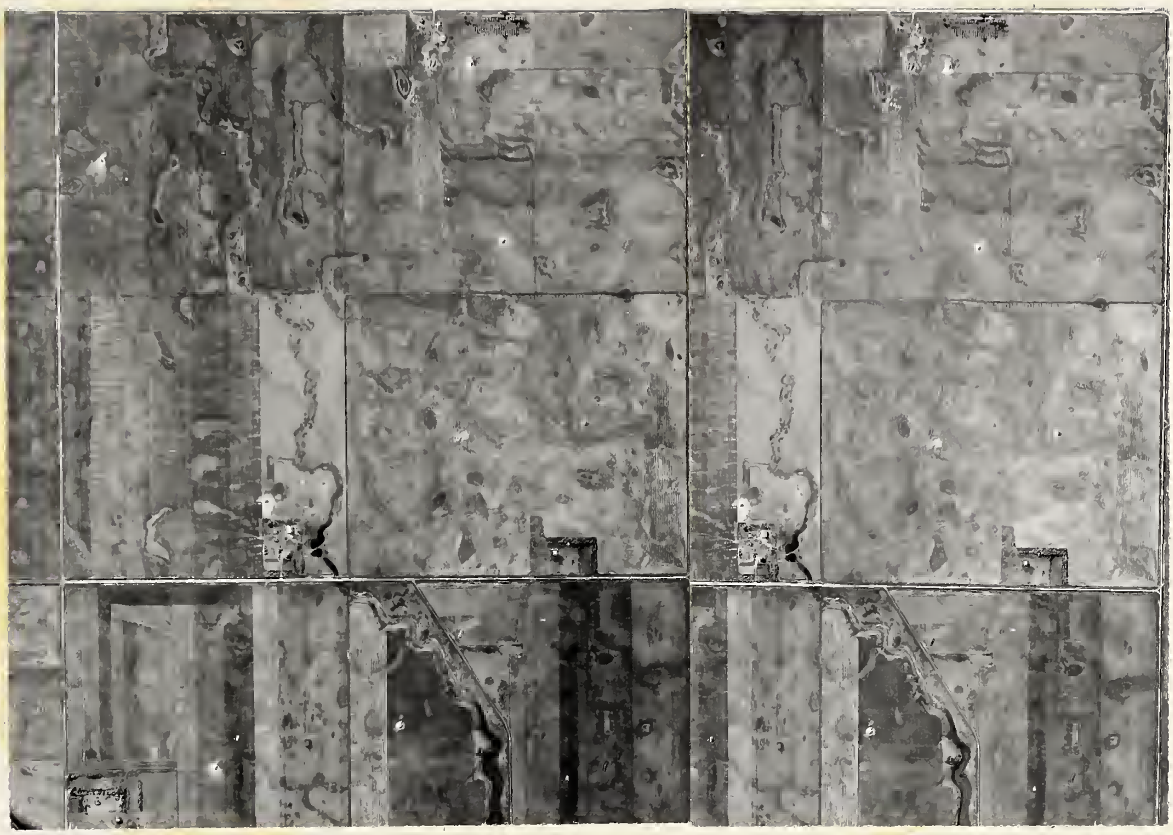


FIGURE 5 — CLOSED DISINTEGRATION RIDGE MAPPED ON A SCALE OF 1" TO 50' SW1/4, 29-157N-85W

CARPIO AREA.

SCALE.

0 100 200 FEET

CONTOUR INTERVAL ONE FOOT

feature was quite easily detected on the ground and was mapped with a plane table and alidade (Fig. 5). The southeast quarter of the section contains a double-rimmed depression, 1600 feet long and 1100 feet wide, with an oval shape in plan view. The rims, about 150 feet wide, are separated by a shallow depression that is hardly perceptible to an observer on the ground but the central depression is easily detected, as the bottom lies six feet below the ridge crests (Fig. 3D).

Prairie mounds marked by one or more depressions were noted in section 3, township 156 N., range 86 W. (Photos BAM-64R-79,80; Plate VA; Fig. 4E). A circular form 500 feet in diameter and about five feet high, has three pits about 16 feet in diameter arranged in a triangular pattern across the upper surface (Fig. 3B). Identical forms, 300 to 500 feet in diameter, appear in section 32, township 157 N., range 85 W. (Photos GS-CD-368,369; Fig. 4F).

Eskers -

An esker complex trends in a northwest-southeast direction across section 29, township 157 N., range 84 W. (Photos GS-DC-365,366; Fig. 4A) and is roughly parallel to the trend of a nearby spillway. Ridges 150 feet wide and 10 to 15 feet high form a trend continuous for a distance of three and one-half miles, terminating at the head of one of the gulleys in the side of a spillway. Two branches join to form a main ridge which in turn splits around a series of small depressions to join again in a single ridge. The crest, very markedly white-mottled, is even for some distance, then breaks up into a series of hummocks or low ridge segments, that are similar to scatterd forms

nearby. The trend and irregular ridge crest are easily detected on the ground.

Depressions -

Although depressions are very common in the Carpio and Tolley areas, they are not, as a rule, sharply outlined. Small forms, circular to oval in plan and less than 400 feet in diameter, show up the best on the air photos.

Typical forms, 100 to 400 feet in diameter and five feet deep, occur in sections 7 and 18, township 159 N., range 86 W. (Photos BAJ-17-10,11; Fig. 4D). The bottoms of the depressions are flat or slightly concave upwards, and the sides slope gently towards them.

The depressions outlined on topographic sheets contoured at five foot intervals were counted and measured in sections 4, 9 and 10, township 158 N., range 86 W., sections 29 and 30, township 157 N., range 85 W. and sections 28, 31 and 33, township 158 N., range 85 W. One-hundred and eighteen depressions 200 to 1600 feet in length (Fig. 7H) were counted and found to average 15 per square mile. Forms rectangular, irregular, circular and oval in plan view, occur in a ratio of 2:3:4:6.

Meltwater Channels -

Meltwater channels are common features which in places occur as extensions of the larger gulleys connected to the spillways in this area.

Section 3, township 156 N., range 86 W. (Photos BAM-64R-79,80; Plate VA; Fig. 4E) contains meltwater channels. One continuous channel

80 feet wide and up to 15 feet deep, crosses the section. The walls of the channel are fairly steep, and where the bottom is flat, recent erosion and vegetation along the channel course, shows up as dark spots on the air photos, as indicated by field examination. In places the channel becomes V-shaped and the flat-bottomed area is absent. Short channels originating in kettles join the main channel or else occur as discontinuous segments, terminated by hummocks or prairie mounds. A section of channel about 800 feet long, 30 feet wide and five feet deep, paralleling the continuous channel, appears to be blocked by a prairie mound as that part of the mound edge considered to be lying across the channel, has a faintly outlined, shallow, linear indentation across its surface, suggesting that the feature was superimposed upon the meltwater channel. Features in this section were examined in the field.

C. Jamestown area, North Dakota

The study area lies within the southeastern part of North Dakota, between latitudes 46° 52' and 47° N. and longitudes 98° 30' and 98° 51' W. (Fig. 1).

Vertical air photos with a scale of one inch to one mile, of an area of about 80 square miles, were made available for study through Dr. W.M. Laird, State Geologist, North Dakota. Topographic sheets with a scale of 2.6 inches to one mile and contoured at five-foot intervals accompanied the photos and were used to determine relief and approximate heights of individual features in areas designated as ground moraine by Laird (personal communication).

Drift forming the surface was deposited during the Mankato substage (Kresl, 1956, map) by ice moving in a generally northeast-southwest direction (N.R.C. Washington, D.C., 1959, map). Several large spillways form the major topographic features in this area.

Nature of the Surface

The surface with relief from 5 to 20 feet, is characterized by hummocks, disintegration ridges and depressions. Northeast of Jamestown, ridges and hummocks appear randomly oriented, whereas the area lying immediately east and southeast of Jamestown contains distinct washboard ridges forming broadly lobate patterns. Depressions are well defined in the area containing the randomly oriented features, but in the vicinity of washboard ridges, depressions become subdued in outline and in some sections they are replaced by open depressions formed by the deposition of the ridges.

Drainage Pattern

No integrated drainage pattern is evident on the drift surface. Small channels showing some evidence of recent erosion occur as extensions of gulleys terminating in the large spillways, and the majority of channels extend only a short distance across the drift surface.

Surface Features

Hummocks

Hummocks with light-colored tops are fairly common features in the area lying northeast of Jamestown. They are from 50 to 500

feet in diameter and average about five feet in height. Sections 33 and 35, township 140 N., range 63 W. (Photos VV-BE-M6-AMS-550,551) contain hummocks that occur both as isolated features and as closely spaced and aligned features forming irregular-crested ridges. Hummocks in this area are as a rule circular to oval in plan but a few irregular forms 5 to 15 feet in height are present in section 35.

Linear Disintegration Ridges

Disintegration ridges are the dominant features over most of the drift surface. Lengths range from 500 to 6000 feet, widths from 50 to 300 feet and heights from 5 to 10 feet.

Randomly oriented ridges appear with a jumble of hummocks in sections 4, 16 and 21, township 140 N., range 63 W. (Photos VV-BE-M12-AMS-1353,1354). Crests of the ridges may or may not be mottled. In the southwest quarter of section 4, two straight ridges with mottled crests parallel each other, separated by a distance of 750 feet. They are 4000 and 6000 feet in length, about 250 feet in width and five feet high. Another ridge in section 16 is 1200 feet long, 150 feet wide and about 10 feet high. The end of the ridge is split by a small depression and terminated by a hummock.

Rather indistinct ridges about 50 feet wide occur in section 25, township 140 N., range 65 W. (Photos VV-BE-M5-AMS-547,548). A chain-like ridge is made up of individual 'links', oval in plan, 300 feet long, 130 feet wide and 5 to ten feet high. Some of the links appear to be closed ridges; other are best described as two arcuate ridge segments lying with their concave sides facing each other. The

trend of the chain-like ridge parallels a subdued washboard ridge pattern in the area. A cluster of randomly-oriented, white-crested ridges, that lie upon the surface of an irregular mound 15 feet high covering about a third of a square mile, appears in the vicinity of the chain-like form. These superimposed ridges appear to be less than five feet high and 150 feet in width; straight, hook-shaped and sinuous outlines impart a vermicular appearance to the surface.

Washboard Ridges

The drift surface immediately southwest of sections 4, 16 and 21, township 140 N., range 63 W., across the James river, contains ridges oriented in very distinct parallel trends. Light-colored mottled crests characterize some of the ridges; many have color tones only slightly lighter than inter-ridge areas. Segments usually are from 500 to 4000 feet in length and in some cases may be continuous for distances greater than one mile. Widths are in the order of 150 to 300 feet and heights are about five feet.

Typical forms are found in sections 1 and 14, township 140 N., range 65 W. (Photos VV-BE-M5-AMS-547,548). In section 14 individual ridges are indistinct but the trend shows up well. Spacing of the ridges in section 14 and adjacent areas is from 300 to 1000 feet with an average (for 14 ridges) of 500 feet.

Depressions

Depressions occur on most of the drift surface, but as a rule they are not major features. Many of them are difficult to distinguish on photos because the bottoms show little contrast in color with adjacent

areas. However, in areas where parallel ridges are not apparent a few depressions do exhibit dark bottoms, and show up well on the air photos. Measurements, orientations and counts were taken from topographic sheets. Data taken from fourteen sections in township 140 N., ranges 63, 64 and 65 W., and township 139, range 65 W., indicated depressions are usually 200 to 1500 feet long and average six per square mile (Fig. 7F). Shapes of depressions vary from more common oval, rectangular and irregular forms to less common circular forms 150 feet in diameter; these shapes occur in a ratio of 6:3:3:1.

Meltwater Channels

Features that may have originated as meltwater channels occur as extensions of gulleys that terminate in the spillways crossing the area. Gulleys exhibit marked recent erosion and extend for distances of from less than one-half mile up to five miles across the drift surface.

D. Tipton, Decatur and Shelby Counties, Indiana and Champaign County, Illinois

These study areas lie in a belt through west-central Indiana and east-central Illinois and are enclosed by latitudes 39° 15' and 40° 30' N. and longitudes 85° 15' and 88° 30' W. (Fig. 1).

Vertical air photos with a scale of one inch to 1760 feet of fifty square miles of ground moraine were made available for study through Dr. C.P. Gravenor of the Research Council of Alberta. A few selected areas were described in detail.

Surface deposits within this belt are Illinoian and Wisconsin in age (Gravenor, personal communication).

Nature of the Surface

Positive features appear to be absent from the surface of Illinoian deposits, and are highly subdued on the drift surfaces of Wisconsin age. Relief averages about five feet. Subdued outlines of ridges and hummocks show up as white patches and spots forming outlines that in plan view bear a strong resemblance to the patterns typical of parts of drift surfaces in western Canada and the north-central United States. Channels similar to the meltwater channels described in other areas are also present. Only rarely can the faint outline of a depression be distinguished.

Drainage Patterns

Well-developed dendritic drainage was noted on the otherwise featureless drift of Illinoian age; on surfaces of Wisconsin age, the drainage does not appear to be integrated.

Surface Features

Hummocks -

Distinctly outlined hummocks do occur in a few places but over most of the area they are much subdued and appear as white-topped, low rises that grade into the light-greys of adjacent hollows. An area within Shelby County (Photos FN-1B-117,118) contains hummocks that in places are aligned to form ridges. Forms circular and oval in plan are from 60 to 500 feet in diameter or length and average less than

five feet in height. Irregular forms are also present and where they occur with circular hummocks and ridges the surface has a convoluted appearance. Tipton County (Photos BWM-3-28,29) has identical features, except that their outlines are even more subdued. One distinct conical hummock 450 feet in diameter and 10 feet high was noted in this area. Similar forms are apparent in Champaign County (Photos AP-1A-81,82) where they are seldom under 150 feet in diameter and reach diameters of 800 feet.

Linear Disintegration Ridges -

Disintegration ridges appear on drift surfaces of Wisconsin age with lengths from 150 to 1800 feet, widths from 60 to 350 feet and heights averaging less than five feet (Fig. 4C). Forms straight, arcuate, hook-shaped and sinuous in plan occur. Tops are usually an even, white color although Shelby County (Photos FN-1B-117, 118) contains a few forms with mottled crests. Patterns of ridges in parts of this area have a vague similarity to washboard ridges.

Meltwater Channels -

A few shallow channels which may have originated as meltwater channels mark parts of the drift surface. One such channel, 200 feet wide and 10 feet deep, crosses the area studied in Shelby County (Photos FN-1 B-117,118). A similar feature in Champaign County (Photos AP-1 A-81,82), continuous across the strip covered by the photos, is joined by numerous short branches that show up as dark, pencil-like lines on the light-colored surface.

E. West Butte and Kevin areas, Toole County, Montana

The northern boundary of the area under study is eleven miles south of the International Boundary between latitudes 48° 45' and 48° 50' N., and longitudes 111° 30' and 111° 55' W. (Fig. 1).

Vertical air photos, with a scale of one inch to 1760 feet, of an area of about 100 square miles, were made available for study through Mr. R.W. Lemke of the United States Geological Survey. A photo mosaic with a scale of one inch to the mile and a topographic map with the same scale (contour interval 25 feet), accompanied the photos. Ground moraine areas were indicated on the photo mosaics. Field checks were carried out in areas described in detail.

The Sweet Grass Hills rise 3400 feet above the level of the drift plain and lie approximately five miles northeast of the northeast corner of the study area. An ice lobe moved through this area in a southeasterly direction (Colton _et al_, 1952, p. 1360), with some local variations as indicated by fluting in the southwest portion of the study area. The drift is probably of Tazewell or Cary age (Flint, 1947, p. 275).

Nature of the Surface

Relief within the area studied approaches 75 feet and local relief of 50 feet is common along stream channels originating in or crossing this area. Within areas described in detail relief ranges from 5 to 25 feet. Postglacial erosion is evident on and between positive elements on the drift surface, and valleys show the effects of such erosion by forming clearly outlined drainage patterns between

Explanation Plate VI - West Butte area

A - Photo numbers - ZQ-3H-29,30; scale 1" to 1760';
Location: parts of sections 5 and 8, township 35 N., range 1E.
Channel-like lineations appear as dark streaks trending northeast-southwest. The northwest-southeast lineations in this area may be the result of ablation debris superimposed upon broad glacial grooves (Fig. 4G).

B - Ground view of the drift surface in the same locality as that shown in the stereo-pair above, only about one mile north. The surfaces appear identical on air photos.

and sometimes across long, arcuate disintegration ridges and fluting. The low to intermediate relief surface is in places marked by dark streaks trending northeast-southwest (Plate VIA; Fig. 4 G) which parallel a nearby belt of aligned hummocks that form washboard ridges. Associated with the aligned ridges are sections where only hummocks and randomly-oriented ridge segments are present. Fluting is superimposed upon large ice disintegration forms in part of the area, while elsewhere disintegration ridges appear to be superimposed upon fluting.

<u>Drainage Pattern</u>

Sharply-defined dendritic to parallel drainage patterns are developed on the drift surface in this region. Narrow and shallow branch channels occur in areas of low relief.

<u>Surface Features</u>

Hummocks -

Hummocks similar to forms described in other areas occur locally and in a few sections they are the only surface features.

Sections 15 and 16, township 35 N., range 1 E. (Photos ZQ-3H-126,127), along the margin of a stream valley 1600 feet wide and 50 feet deep, contain hummocks 200 to 500 feet in diameter, 5 to 10 feet high and circular to oval in plan. Tops are smooth-textured and only slightly lighter than adjacent areas. Where the surface is cultivated they are very subdued.

Linear Disintegration Ridges -

Sections 11 and 12, township 35 N., range 1 W. (Photos ZQ-

3H-28,29; Fig. 4B) contain straight to arcuate disintegration ridges as well as elements that appear to be fluting. The ridges are 1000 to 3000 feet long, 100 to 150 feet wide and 10 to 20 feet high. Crests are irregular in section (a characteristic also apparent in the field) and are marked by white patches.

Single ridges may extend several miles, with offsets of about 100 feet in places. Slight variations in orientation result in an arcuate ridge trend, concave to the northeast. Sometimes only an isolated ridge segment occurs, with the general northwest-southeast trend. Spacing between ridges ranges from 300 to 600 feet.

The disintegration ridges appear to be superimposed upon fluting as indicated by a few straight, even-crested ridge segments that may represent the positive elements of fluting.

In sections 15 and 16, township 35 N., range 1 E. (Photos ZQ-3H-125,126) indistinct ridges associated with hummocks, trend in a northeast-southwest direction, and give rise to washboard ridge patterns. In a part of this area, the pattern disintegrates into a maze of hummocks and ridge segments. Two prominent ridges 1400 feet long, 200 feet wide and 600 feet apart, are aligned with the nearby washboard ridges.

Closed Disintegration Ridges -

Only a few large closed ridges of intermediate relief were noted in the study area. In sections 28 and 33, township 35 N., range 2 W. (Photos ZQ-3H-174,175), an irregular closed disintegration ridge 400 to 1000 feet wide and 15 to 25 feet high forms a depression

1400 feet long and 800 feet wide. Part of the ridge is straight and relatively narrow with a crest that appears even on photos but was noted to be irregular in section when examined in the field; a wider and higher portion of the ridge is marked by a much more irregular crest. Fluting is faintly evident across the broader portion of the closed ridge. Both fluting, and closed ridges are composed of stoney till.

Section 13, township 35 N., range 1 E. (Photos ZQ-3H-125, 126) contains prairie mounds 150 to 300 feet in diameter and about five feet in height. Depressions marking the surface of these features are about 20 feet across, appear very shallow and show up as a dark spot on the air photos. A nearby cultivated section is marked by identical dark spots suggesting the presence of similar forms.

Washboard Ridges

Subdued forms of washboard ridges occur in sections 8 and 17, township 37 N., range 1 E., (Photos ZQ-3H-29,30; Fig. 4G), associated with the hummocks described earlier. The ridges are 150 to 250 feet wide and about five feet high with mottled crests and trends that are identical to forms described in the Moose Mountain area, except that the former are more subdued in outline. The washboard ridges grade into a low-relief surface, lying to the northeast, that is marked by hummocks and randomly-oriented ridge segments.

Fluting -

Fluting oriented in a northeast-southwest direction is superimposed upon large, irregular disintegration features in sections

28 and 33, township 35 N., range 2 W. (Photos ZQ-3H-174,175). Positive elements of fluting about 150 feet wide and 3 to 5 feet high, can be traced for distances from 800 to 1400 feet. Spacing between ridge crests is from 600 to 800 feet. Elongate rises and broadly U-shaped linear depressions indicate the presence of these features to an observer on the ground.

Sections 5 and 8, township 35 N., range 1 E. (Photos ZQ-3H-29,30; Plate VIA; Fig. 4G) contain lineations trending southeast. The patterns formed by these features suggest a subdued form of fluting. The positive elements are broadly rounded, 600 to 800 feet wide and can be traced for distances of several thousand feet; a few are continuous for a mile. Spacing between the crests of five of the ridges ranges from 1000 to 1600 feet.

Depressions -

Depressions 300 to 600 feet in length and 5 to 10 feet deep average about two to four to the square mile. Large, constructional type of depressions, from 1000 feet to greater than one mile in length and 5 to 10 feet deep, occur in the west half of the study area.

Meltwater Channels -

Recent erosion has modified the form of features that probably originated as meltwater channels. One such channel in section 5, township 35 N., range 1 E. (Photos ZQ-3H-29,30; Plate VIA) is 40 feet wide, 5 to 10 feet deep and parallels the direction of fluting.

F. Sedgewick and Coronation areas, Alberta

These areas lie in the east-central part of Alberta between latitudes 52° 45' and 53° N., and longitudes 111° 45' and 112° W. (Sedgewick) and between latitudes 52° and 52° 15' N., and longitudes 111° and 111° 15' W. (Coronation). All locations given are west of the 4th meridian (Fig. 1).

Royal Canadian Air Force vertical photos, with a scale of one inch to 3333 feet, of an area of approximately 300 square miles were made available through Drs. C.P. Gravenor and L.A. Bayrock of the Research Council of Alberta. Maps of the glacial geology of these districts (Gravenor and Bayrock, 1955; Gravenor and Ellwood, 1957) were used to delimit areas of mapped ground moraine. Several of the localities described in detail were checked in the field.

Glaciers of Wisconsin age (Stockwell, 1957, p. 482) moved through the area in a southeasterly direction (Gravenor and Ellwood, 1957, p. 25). Both districts lie within, or partly within, a relatively flat plain where the till cover is thin and topography is controlled in part by bedrock (Gravenor and Bayrock, 1955, p. 11). The study area forms part of a drift surface known as Torlea Flats, a north-south trending belt about 200 miles long and 25 to 50 miles wide bounded on its eastern and western margins by the Buffalo Lake and Viking moraines - formerly referred to as end moraines and currently believed best described as dead-ice moraines (Gravenor and Ellwood, 1957, p. 12).

Nature of the Surface

Hummocks, low disintegration ridges and depressions are very common forms on the drift surface. Relief ranges from 5 to 20 feet.

In the Sedgewick area the overall surface pattern is one of broad, low rises separated by hollows. Hummocks, linear disintegration ridges and depressions are common. A few closed disintegration ridges, crevasse fillings and small kames mark the surface. Tree-ringed depressions of various shapes and sizes, averaging about 500 feet in length, are dominant features in parts of the area. These in turn may grade into smooth, even-toned surfaces or into areas having a mottled-white or finely-speckled appearance. A low esker-like ridge was noted to be superimposed on fluting in one locality.

Several localities in the Coronation area contain features that are the direct expression of pre-drift topography or that exhibit patterns strongly indicative of bedrock control. Contorted bedrock forms a series of broadly arcuate and concentric ridges in an area mapped as thin ground moraine (Fig. 6B). Patterns exhibited by meltwater channels appear to be the result of bedrock control.

Drainage Patterns

Dendritic to rectangular drainage patterns are formed by meltwater channels and stream trenches. The main drainage channels are formed by Ribstone and Iron creeks and tributaries show the effects of intermittent stream erosion.

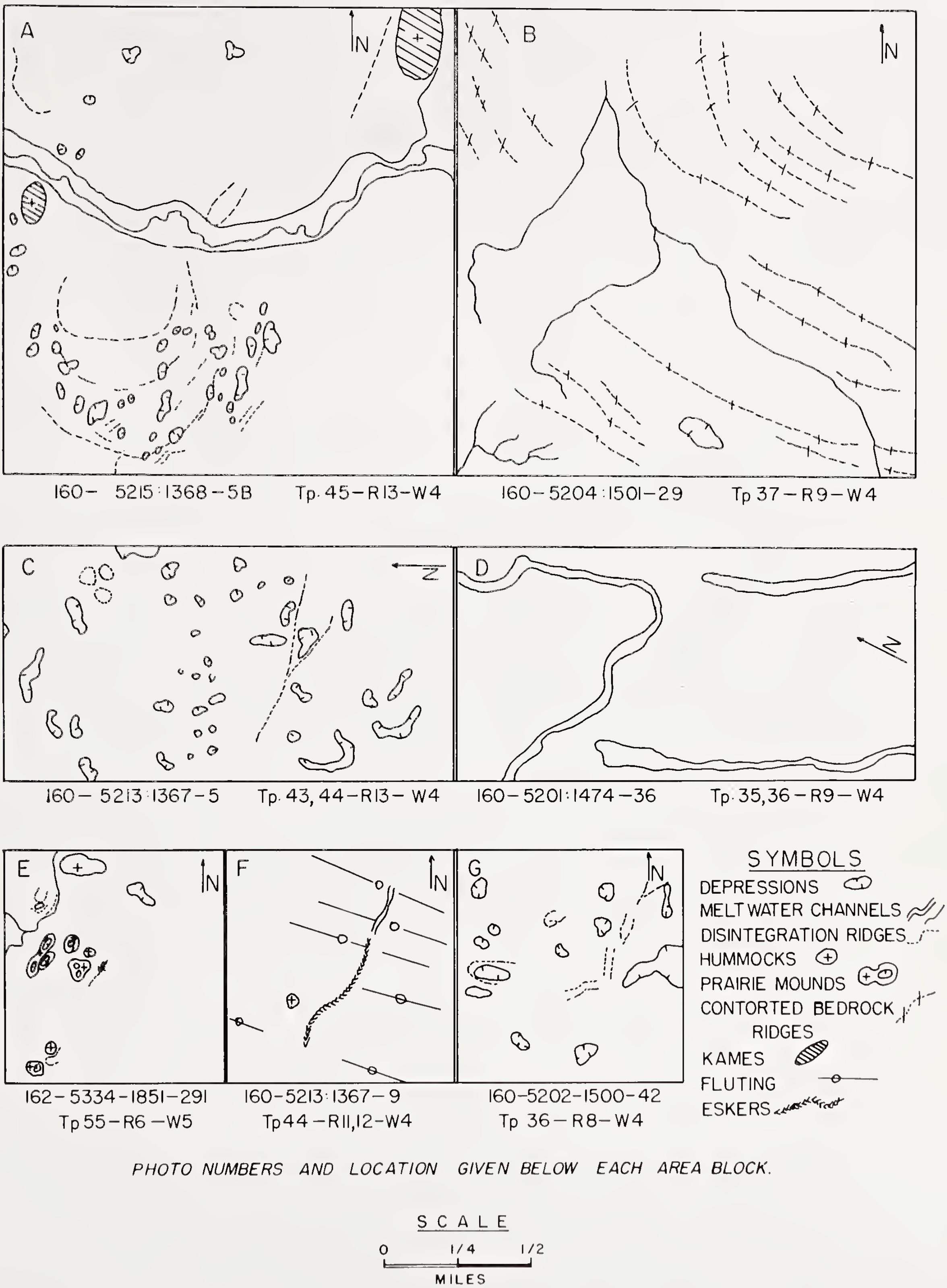


FIGURE 6 PATTERNED SURFACE FORMS WITHIN AREAS MAPPED AS "GROUND MORAINE" ALBERTA

Surface Features

Hummocks -

Hummocks appear as low forms with light-colored tops and are 150 to 250 feet in diameter and from less than 5 up to 10 feet in height. Typical forms occur in patches throughout townships 45 and 46, range 14 and are frequently associated to form linear and sometimes closed disintegration ridges.

Linear Disintegration Ridges -

These features appear as well-defined or subdued forms over most of the drift surface. Within township 37, range 10 (Photos 160-5203-1501-34,35), adjacent to a channel about 500 feet wide and 20 feet deep, short ridge segments about 200 feet long, 80 feet wide and 5 to 10 feet high appear with hummocks and depressions. Two straight forms 1200 and 1600 feet long, 80 and 160 feet wide and 10 and 20 feet high, are distinctive features.

In township 45, range 13 (Photos 160-5215-1368-5B,6B; Fig. 6A, part of area) a series of ridge segments and hummocks form irregular crested ridges. One such ridge in section 15, 1600 feet long, 240 feet wide and about 10 feet high, has a mottled white crest and in places is composed of aligned hummocks and short ridges slightly offset from the main ridge trend. A similar feature 1000 feet long and 120 feet wide, of about the same height, joins the above ridge at an acute angle. Some of the segments making up the ridge are identical to closely associated features mapped as crevasse fillings. The crevasse fillings are straight forms that appear smooth-surfaced

and even-crested on air photos, but when observed on the ground, their irregular crests become evident. One of these forms lying across the boundary of sections 16 and 21 is about 3000 feet long, 150 to 300 feet wide and 5 to 20 feet high (Plate VIIA). The portion lying in section 16 represents the largest part of the feature (Plate VIIIA) and is very distinctive even when observed in the field, as it rises abruptly from the gently rolling surface in marked contrast to the low rises characteristic of other sections of this feature (Plate VIIB).

Section 36, township 43, range 14 (Photos 160-5213-1367-4,5; Fig. 6C, part of area) contains three linear disintegration ridges mapped as crevasse fillings. They appear as even-crested, smooth straight ridges 1000 to 3000 feet long, 120 to 160 feet wide and less than five feet in height. Two join at an acute angle and the third is slightly offset from, but parallel to one of the joined ridges. The trend of these ridges cannot be discerned on the ground and is marked only by a series of low rises. A number of similar forms appears about a miles east of section 36.

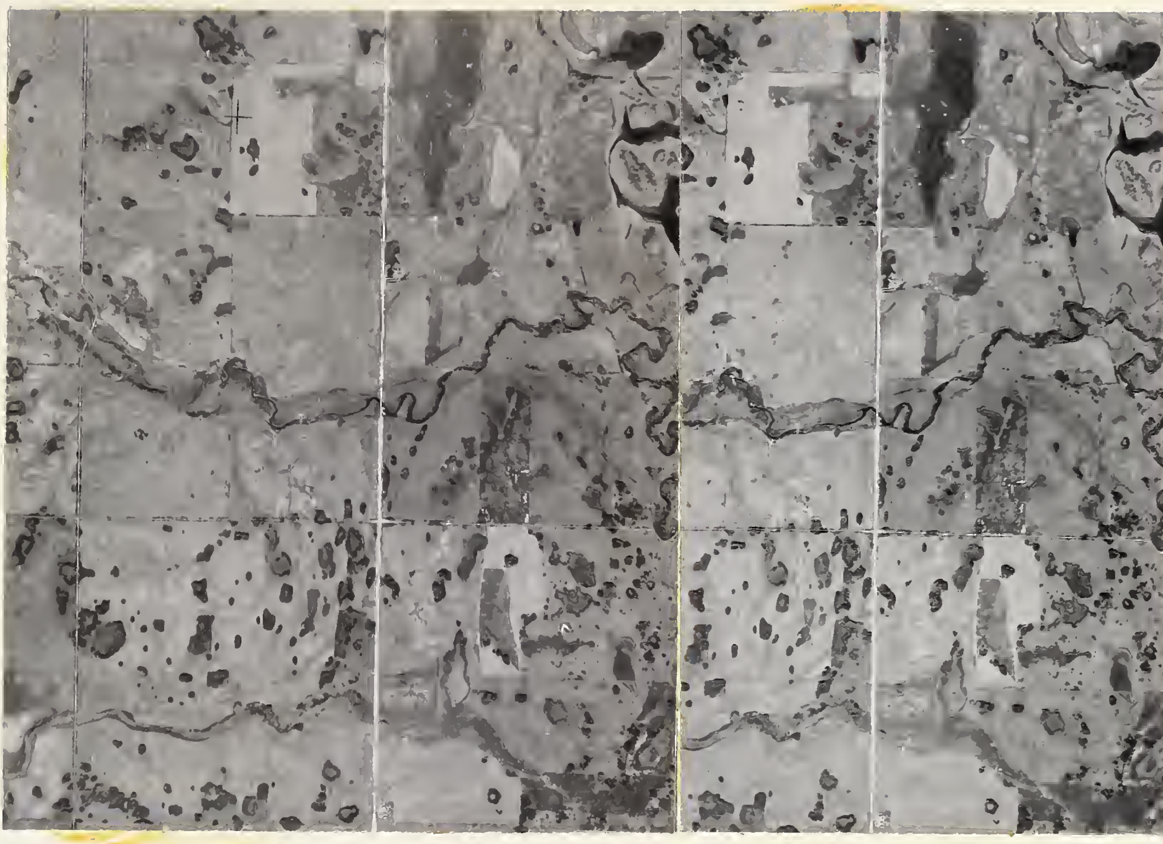
A cluster of depressions, hummocks and ridges form a horseshoe-shaped feature in section 8, township 45, range 13 (Photos 160-5215-1368-4B,5B; Plate VIIA; Fig. 6A). This fairly indistinct form is about 20 feet high, covers an area of approximately one square mile and is bounded by a stream trench on the north and a meltwater channel on the south. The feature appears to consist of three parts separated by shallow ravines; an outer belt is subdued in outline and is formed by a series of hummocks and depressions, as is the cresent-

Explanation Plate VII - Sedgewick area

A - Photo number - 160-5215-1368-5B,6B; scale: 1" to 3333';
Location: sections 9, 16 and 21, township 45, range 13, W. 4th.

This area contains crevasse fillings and the horseshoe-shaped form described in the text. The 'X' in the upper right-hand corner of the stereo-pair marks the location from which ground view photos of a crevasse filling were taken and the horseshoe-shaped form lies in the lower left-hand corner (Fig. 6A).

B - Ground view, looking towards the northeast, of the crevasse filling mentioned above.



Explanation Plate VIII - Sedgewick area

A - Ground view looking towards the southwest of crevasse fillings in Plate VIIA. The location is marked by an 'X' in the upper right-hand corner of the stereo-pair.

B - Ground view, looking towards the northeast, of cuts in fluting believed formed by the meltwater that deposited the esker in Plate IXA. The location is marked by an 'X' in the upper central part of the stereo-pair.

shaped central part which in turn is followed by a more distinct innermost, plateau-like rise. Small depressions lie adjacent to and between the ridges and hummocks. Similar surfaces lacking the distinctive form of the above feature occur in places along the margin of the stream trench.

Closed Disintegration Ridges -

Closed disintegration ridges are not very common features within this area. A few subdued forms are present in section 24, township 44, range 14 (Photos 160-5213-1367-4,5; Fig. 6C). Ridges about 40 feet wide and less than five feet in height close to form circular features about 500 feet in diameter.

Fluting -

Fluting occurs within and immediately adjacent to a large meltwater channel crossing township 44, range 12 (Photos 160-5213-1367-9,10; Plate IXA; Fig. 6F). Positive elements within all or parts of sections 11, 12, 13 and 14, are 2500 to 3200 feet long, about 300 feet wide and 5 to 20 feet high with spacing between crests in the order of 500 to 1000 feet. Six distinct, straight ridges and grooves form a corrugated surface. The higher ridges are very prominent in the field and have markedly level crests and smoothly-rounded cross-sections. The largest ridge, lying near the northern edge of the fluted area, ends very abruptly, a characteristic that can probably be attributed to erosion by meltwater (Plate IXB).

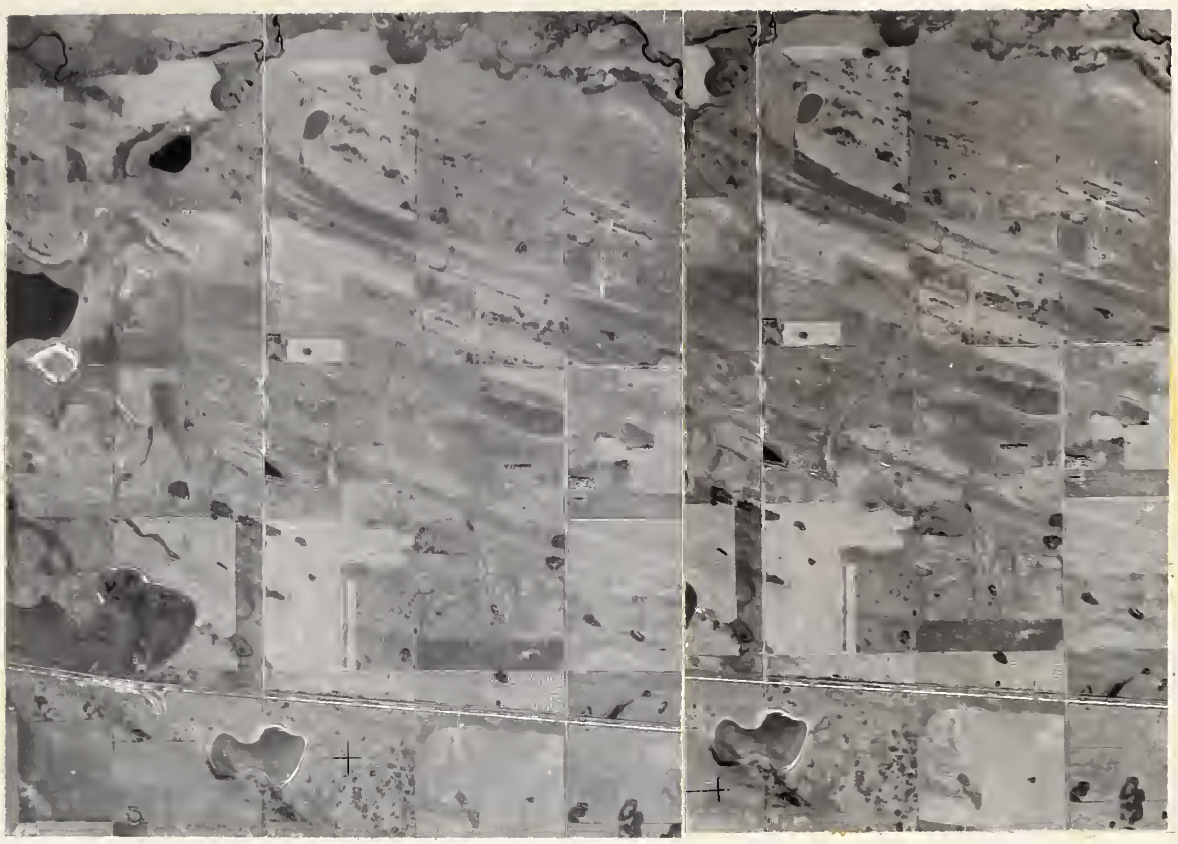
Eskers -

An esker and outwash deposits are superimposed upon part of

Explanation Plate IX - Sedgewick area

A - Photo numbers - 160-5213-1367-9,10; scale: 1" to 3333'; Location: sections 11 and 14, township 44, range 12, W. 4th. This area contains fluting with an esker and outwash superimposed upon the portion lying in the central part of the stereo-pair. Note the cuts in the ridges formed by the meltwater that deposited the esker.

B - Ground view of the abrupt termination of the most prominent ridge in the fluted area looking towards the southwest. The location is marked by an 'X' in the upper left-hand corner of the stereo-pair.



the fluting in township 44, range 12 (Photos 160-5213-1367-9,10; Plate IXA; Fig. 6F). These features lie across the fluting in the vicinity of the boundary between sections 11 and 14. The esker lies at right angles to the fluting and is about 3600 feet long, 150 to 250 feet wide and is five feet or less in height. It is terminated by a small fan and where a ridge is no longer evident in its upstream portion, U-shaped cuts, through the positive elements of the fluting, align with the esker trend, indicating erosion by the stream that formed the esker. The esker is apparent on the ground as a sandy ridge, and the U-shaped cuts also show up well (Plate VIIIB).

Kames -

Small kames were noted here and there on the drift surface. Typical forms occur in section 13, township 44, range 14 (Photos 160-5213-1367-4,5). Two of them, mapped as kames, are 1200 and 1400 feet in length, 500 feet wide and about 10 feet high and roughly oval in plan.

Depressions -

Depressions are common to the drift surface although their frequency of occurrence varies locally. Forms oval, rectangular and irregular in plan are the rule. Within township 44, range 14, they are usually from 200 to 1000 feet in length and less than 10 feet deep. A count of depressions in five sections indicated that forms from 200 to 1000 feet in length average 12 per square mile.

In townships 45 and 46, range 14, lengths of depressions are from 400 to 800 feet and depths are less than 10 feet. Forms greater

than 200 feet in length average 12 per square mile within an area of eight square miles.

Large depressions are common in the vicinity of township 35, range 9 in the Coronation district. Lengths range from less than 300 to 3600 feet and depths from 5 to 15 feet. Forms greater than 200 feet in length average four per square mile over an area of 16 square miles.

Meltwater Channels -

Meltwater channels occur in the vicinity of stream trenches and form dendritic to rectangular patterns across most of the drift surface. A typical shallow channel about 40 feet wide lies in a valley 800 feet wide and 20 feet deep crossing section 13, township 44, range 14 (Photos 160-5213-1367-5,6).

Parallelism and angular bends exhibited by channels in the Coronation district suggest that this pattern is affected by underlying bedrock, inasmuch as the till in this area ranges in thickness only from 10 to 30 feet (Fig. 6D) (Gravenor and Bayrock, 1955, p. 34-35).

G. St. Ann area, Alberta

The St. Ann area is about 60 miles northwest of Edmonton. The locality under study lies within township 55, range 6, west of the fifth meridian (Fig. 1).

Vertical air photos with a scale of one inch to 1320 feet were made available for study through the National Research Council Grant. A surficial geology map (Collins and Swan, 1955) was used to delimit areas of mapped ground moraine.

This area lies between the plains region to the east and the foothills to the west, on a surface sloping gently to the northeast. Wisconsin glaciers (Stockwell, 1957, p. 482) moved through the area in a southeasterly direction (Gravenor and Ellwood, 1957, p. 26).

Nature of the Surface

Moderate to heavy tree and brush growth covers much of the surface. Local relief is from 5 to 35 feet. Small undrained lakes are common and low areas are often flat and boggy - a fact that may be attributed to postglacial infilling by lake deposits. The tree cover over a large part of the area has been removed for agricultural purposes, thus exposing an irregular drift surface. In the vicinity of sections 16, 23, 24 and 26, the cleared surface is generally smooth with alternating light- and dark-colored patches. The light-colored patches are not necessarily confined to elevated areas. Prairie mounds are the most distinctive feature in this area, which also contains subdued forms of hummocks, irregular ridges and depressions.

Drainage Patterns

The drainage of this area is deranged.

Surface Features

Hummocks -

Hummocks are uncommon, but irregular mounds equal to, or greater in size than prairie mounds in this area are common.

Linear Disintegration Ridges -

The ridges are rather subdued in outline and merge into

hummocks with similar poorly-defined boundaries. Typical forms are 250 to 600 feet long, 100 to 150 feet wide and 5 to 20 feet high.

Closed Disintegration Ridges -

Prairie mounds are very common forms of disintegration features in this area. Some forms are well defined while others are rather indistinct in outline. In section 23 (Photos 162-5334-1851-291,292; Plate XA; Fig. 6E) two circular prairie mounds, 240 and 370 feet in diameter, five feet high have a shallow depression marking the surface and represent the typical form. A form heart-shaped in plan, containing one indistinct and two distinct depressions about 10 feet deep, is 600 feet long, 500 feet wide and 30 feet high and has its outer ridge broken by a channel. Next to the above feature is a combination of two elongated prairie mounds joined like two links in a chain. A small semi-circular prairie mound joins the side of the larger 'link'. This combined form is 900 feet long, 320 feet wide and 25 feet high with an elongated central depression 10 feet deep. All of the above mentioned characteristics are easily detected on the ground (Plate XB). The channels appear as U-shaped cuts through the ridges.

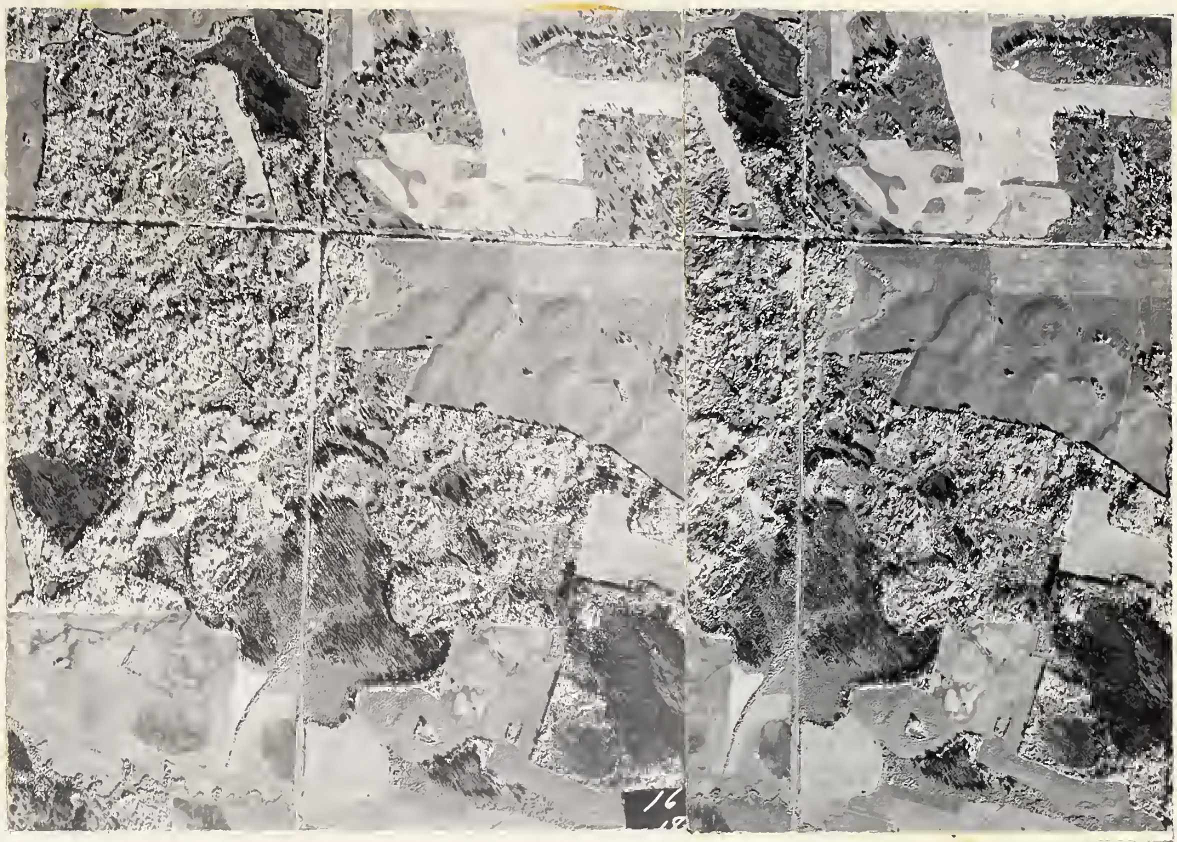
Prairie mounds in sections 15 and 16 (Photos 162-5333-1850-350,351,352) exhibit a few more variations of surface form. Color tones and surface textures are similar to adjacent negative and positive areas. One feature in section 15, 580 feet in diameter and 9 feet high has an upper surface marked by two concentric ridges and a small hummock in the center. The outer ridge is continuous but the inner one consists of a series of segments along with a shallow, off center

A

Explanation Plate X - St. Ann area

A - Photo numbers - 162-5334-1851-291,292; scale: 1" to 1320'; Location: section 23, township 55, range 6, W. 5th. This area contains various types of prairie mounds (Fig. 6E).

B - Ground view of the prairie mound marked by an 'X' in above stereo-pair looking northeast across the larger 'link' of the link-shaped form. The meltwater channel apparent on the northwest side of the feature in the stereo-pair is marked by an 'X' on the ground view of this feature.


16

depression. Another form in the immediate vicinity is 500 feet in diameter and five feet high. Its upper surface is flat and rimmed by a ridge 60 feet wide and two feet high. A cluster of trees lying just inside the ridge indicates a depression oval-shaped in plan and 200 feet long. A prairie mound, in section 16, oval in plan, 700 feet long, 580 feet wide and 6 feet high, has an upper surface marked by a series of concentric ridge segments that impart a 'collapsed' appearance to the surface. An elongated mound in the same section is made up of two crescent-shaped ridges with concave sides opposed to each other, forming a feature 1050 feet long, 760 feet wide and 12 feet high. The ridges are 260 feet wide in the middle and taper toward the ends. Trees cover the central low area which appears to be elevated above the general level of the surface outside the ridges.

Depressions -

Depressions marking the surface are as a rule not distinctly outlined in plan. Small depressions mark the surface of most prairie mounds though some may be open forms. Low areas between positive features are often swampy and ringed with brush or trees.

Meltwater Channels -

Narrow, shallow channels, showing no evidence of recent erosion were noted in a few places. A typical channel is 30 to 50 feet wide, has five feet of relief and a smoothly-rounded or flat bottom. The channels originate in higher areas and terminate in the bogs.

H. Lindsay-Peterborough area, Ontario

The selected study tracts lie in the vicinity of the south-east shore of Rice Lake, which is about 10 miles north of Port Hope, Ontario, between latitudes 44° and 44° 20' N., and longitudes 78° and 78° 30' W. (Fig. 1).

Vertical air photos, with a scale of one inch to 1320 feet of an area of approximately 12 square miles were made available for study through Dr. C.P. Gravenor of the Research Council of Alberta. A surficial geology map (Gravenor, 1959) with a scale of one inch to two miles was used to delimit areas mapped as ground moraine. The last major ice advance in this area took place during late Wisconsin, probably Valders (Mankato) time (Stockwell, 1957, p. 480). Ice moved through the area in a generally northeast to southwest direction (Gravenor, op. cit).

Nature of the Surface

The ground moraine within this area occurs in patches and is characterized by drumlin fields trending northeast-southwest. Extensive glacio-fluvial deposits occur adjacent to the small patches of ground moraine. Relief ranges from less than five feet on surfaces between drumlins to more than 100 feet for some drumlins. The surface between most drumlins is essentially featureless, with the exception of a few small stream channels and an occasional low ridge form. Two miles northeast of Starkville, about four square miles of ground moraine bounded by glacio-fluvial and lacustrine deposits, lacks the drumlins so common in other parts of this area. The surface here is smooth and

gently rolling and consists of broad shallow valleys with relief ranging from less than 5 feet up to 30 feet, crossed by a sinuous ridge subdued in outline and consisting of straight to arcuate segments, indicative of an esker complex.

Drainage Patterns

A fairly-well integrated dendritic drainage pattern has developed over most of the area. Recent erosion is evident along many of the channels.

Surface Features

Drumlins -

Drumlins and drumlin-like ridges form the only distinct positive surface features. The larger forms are 1500 to 5000 feet long, 400 to 1000 feet wide and 15 to 100 feet high. An area eight miles due north of Coburg (Photos A 1052-63,64) is dominated by drumlins. Surfaces of the drumlins and inter-drumlin areas are smooth and even-toned with shallow grooves evident in some places. Two drumlin-like ridges, subdued in outline, were noted on the surface in the Starkville area (Photos A 140-29,30). They are 480 and 1100 feet long, 30 feet wide and less than five feet high with smooth, light-colored crests and rounded cross-sections.

Eskers -

Eskers are not common in this area. A discontinuous esker in the Starkville area (Photos A 140-29,30) is about 50 feet wide and 5 to 10 feet high. It follows a sinuous course across several low

ridges for about one mile and terminates at the bottom of a valley in a lobe 800 feet long, 500 feet wide and 20 feet high.

Meltwater Channels -

Channels, that may be meltwater forms, are shallow, 20 to 30 feet wide, and show considerable evidence of recent erosion.

I. Tyonek and Talkeetna areas, Alaska

The drift surfaces studied are in the vicinity of Cook Inlet, Alaska. The Tyonek area lies immediately west of the mouth of the Susitna River and the Talkeetna area lies 50 miles north of the above area, along the same river. Latitudes of 61° and 62° 30' N. and longitudes 150° 30' and 151° 30' W., enclose both areas (Fig. 1).

Vertical air photos of ground moraine (Pewe, personal communication) with scales of one inch to 3250 feet and one inch to 4100 feet, of an area of approximately 80 square miles were made available for study through Dr. Troy Pewe of the University of Alaska. Topographic sheets with a scale of one inch to five miles and contoured at 200 foot intervals were also available, but were of little use.

The study areas lie within the glaciated Susitna River valley at elevations less than 400 feet above sea level. The Alaska Range, which reaches elevations 12,600 feet above sea level, forms the western and northern walls of the valley. The Chugach Mountains to the east lie outside the area covered by the topographic sheets. Numerous valley glaciers terminate at points 1000 feet above sea level.

Nature of the Surface

The surface designated as ground moraine is highly dissected by glacial meltwater. Relief on the surface between channels is usually from 10 to 30 feet although the occasional hummock reaches a height of 100 feet. Depth of channels is from 20 to 100 feet. Ridges and depressions appear as distinct features that are, as a rule, rounded in cross section but the occasional feature is sharply angular.

In the Tyonek area several through-going channels and branch channels form a dendritic pattern between irregular ridges, light-colored flats and water-filled constructional depressions. Drumlin-like forms and ridges, rounded or angular in section were noted.

Stream channels in another locality about 15 miles west of the town of Talkeetna form a braided pattern across the valley. Trees and light-colored clearings mark the surfaces of 'islands' between stream channels and form linear patterns that parallel the valley trend. Ridges paralleling the valley trend were noted in a few of the inter-stream areas.

Eighteen miles west of Montana, Alaska the surface is covered by a heavy growth of trees with the occasional boggy area of irregular outline.

Drainage Patterns

Streams form dendritic, parallel and braided patterns across the valley.

Surface Features

Ridge Forms -

The thick tree cover combined with heavy erosion by streams

makes positive identification of ridge forms difficult.

Some of the ridges appear to be drumlin-like forms as indicated by the nature of their surfaces in clearings and their down-valley orientation. One form in the Tyonek area (Photos VV-55-SRW-M 653-0125,0126) has a true drumlin form and is 2000 feet long, 1000 feet wide and 20 feet high. Another ridge is 3200 feet long, 280 feet wide and 15 feet high. A ridge, arcuate in plan, transverse to the valley trend is 1400 feet long, 480 feet wide and 30 feet high with an irregular surface. A sinuous ridge with about the same orientation is 1700 feet long, 280 feet wide, 10 feet high and trails away from one of the drumlin-like forms. A large irregular form 4800 feet long, 1800 feet wide and 100 feet high, parallel to the margin of a channel, occurs in the same area.

Depressions -

Depressions marking the surface in these areas are generally irregular in plan and appear to be of a constructional nature. Many contain water or have boggy bottoms. Lengths usually range from 400 to 1600 feet and depths from 10 to 20 feet. A few depressions with lengths in the order of 4000 feet were noted.

Meltwater Channels -

Channels in this area are usually marked by steep sides and have widths from 400 to 1200 feet with depths of 20 to 100 feet. Some large channels contain misfit streams and the braided pattern evident in parts of the study suggest the presence of outwash deposits.

INTERPRETATION OF RESULTS

A. Features common to drift surfaces of Wisconsin age

Table 1 indicates the relative frequency of occurrence of various features noted in the study areas.

1. General statement

Surface forms, outlines in plan and the patterns exhibited by the features described in the text leave little doubt that they are the direct reflection of both active and stagnant or near-stagnant glacier-ice phenomena. Till surfaces marked by streamlined forms such as drumlins and fluting are indicative of formation by the lodgment of till at the base of an active glacier. Stagnant or near-stagnant glacier-ice conditions appear to have resulted in the deposition of ablation moraine and in the squeezing-up of basal debris into ice-cavities and crevasses to form hummocks, linear disintegration ridges, closed disintegration ridges, washboard ridges and depressions.

The various aspects of streamlined forms, with regard to their formation, is fully discussed in the literature but this is not true of features associated with ice stagnation, particularly in areas of low to intermediate relief. Those aspects of the latter type of feature which are considered to be genetically significant are further discussed.

2. Similarity of surface patterns between modern glacier surfaces and Pleistocene stagnant-ice features

Tarr and Martin (1914, p. 61) describe the surface of the

TABLE I

The relative frequency of occurrence of features on

Wisconsin age drift in the study areas

Areas	Hummocks	Closed disintegration ridges	Linear disintegration ridges	Washboard ridges	Drumlins and drumlin-like forms	Fluting	Kames	Eskers	Depressions	Meltwater channels
Moose Mountain	VC	C	VC	C	A	A	R	R	VC	C
Carpio and Tolley	VC	VC	VC	A	A	A	A	R	VC	C
Jamestown	VC	R	VC	C	A	A	A	A	C	C
Tipton, Decatur, Shelby and Champaign Counties	VC	A	VC	A	A	A	A	A	A	R
Toole County	C	C	C	C	R	C	A	A	C	C
Sedgewick and Coronation	VC	R	VC	A	A	R	C	R	VC	C
St. Ann	C	VC	C	A	A	A	A	A	C	C
Lindsay-Peterborough	A	A	A	A	VC	A	A	R	A	R
Tyonek and Talkeetna	A	R	A	R	C	A	A	A	C	VC

The following quantitative terminology is used:

very common (VC) - indicated features are numerous in every locality (one or two sections) described within the designated area.

common (C) - indicated features are numerous in at least one of the localities described within the designated area.

rare (R) - at least one indicated feature was noted in the designated area.

absent (A) - no feature of the type indicated was noted in the designated area.

Lucia Galcier in Alaska as one of extreme irregularity caused by differential melting and state that "In crossing the ice surface one was constantly climbing over knolls and ridges and descending into valleys, some roughly circular, others linear or crescentic, and the difference in elevation was often fully 100 feet. The elevations occurred where the drift was thick, the depressions where it was thin, and it was evident that the relative positions of these higher and lower portions of the moraine surface were constantly changing as the thickness of the drift changed through downsliding". Surfaces in the vicinity of the terminal margins of modern piedmont and continental glaciers normally carry a debris cover. Certain piedmont glaciers carry ablation debris of sufficient thickness to completely bury the glacier ice and even support heavy tree growth (Tar and Martin, 1914, p. 44). When ablation debris of this nature is deposited it may well form hummocks, linear disintegration ridges, closed disintegration ridges and depressions similar to those observed in the study areas.

Shear plane moraines are prominent features along the fringes of modern polar ice caps (Goldthwait, 1950, p. 567; Schytt, 1955, p. 57) but the debris cover is relatively thin (Schytt, ibid) and clean ice surfaces are the rule away from the immediate ice margin. Crescentic ridges formed up-valley from the peidmont bulb of the Lucia Glacier form a series of subparallel ridges and Tarr and Martin (1914, p. 61), point out that "The cause of this peculiar arrangement of ridges is not clear, but it is in some way connected with the flowage of ice under the conditions of expansion into a piedmont ice bulb of semi-

stagnant or stagnant condition."

The patterns formed by washboard ridges noted in the study areas are similar in plan to the patterns mentioned in the previous paragraph and such ridges may have originated near the terminal margins of Pleistocene glaciers as ablation debris. Channels cut across some of the ridges shown in Plate VA suggest that washboard ridges may also form subglacially; Elson (1957, p. 1721) and Hoppe (1957, p. 5) believe that washboard ridges may form in this manner.

3. Significance of orientation data

Orientation normal to, parallel to, or at 45 degrees to the direction of ice-movement is considered indicative of former ice-flow influence (Gravenor and Kupsch, 1959, p. 53). The orientation of depressions in the Jamestown area (Fig. 7E) and in east-central Alberta (Fig. 8) is indicative of a relationship to ice-movement direction, whereas the orientation of ridges and depressions in other areas is suggestive of such control, but hardly conclusive evidence for it.

Gravenor and Kupsch (1959, p. 48) believe that the landforms particular to areas of former stagnant or near-stagnant ice are closely associated with the formation of ice-cracks. They attribute the formation of ice-cracks to lines of weakness within the ice caused by earlier ice flow, and to separation along these lines of weakness during stagnation or near-stagnation of the ice.

The correlation of orientations with the direction of ice movement lends support to the above concept.

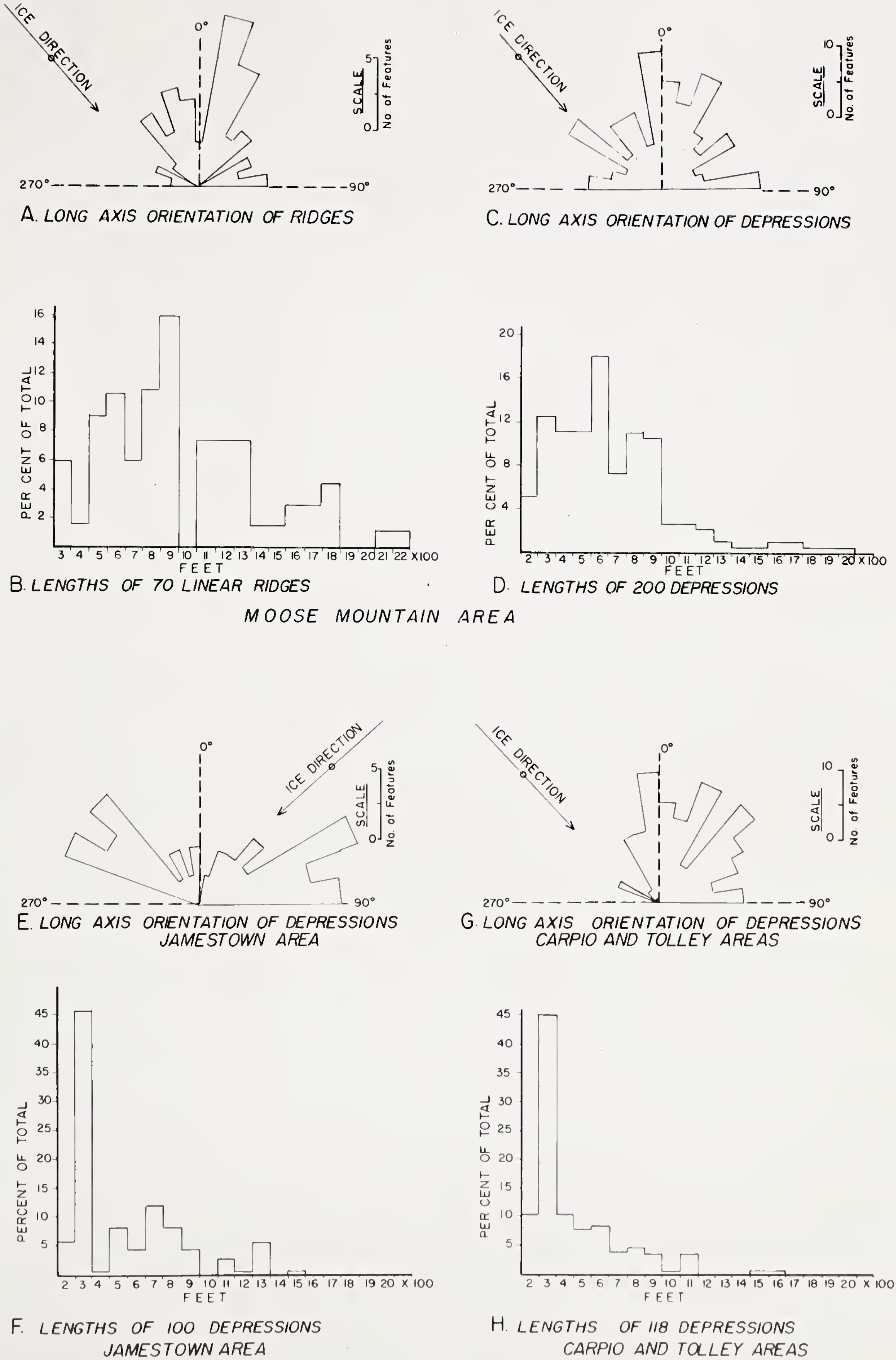


FIGURE 7. ROSE DIAGRAMS AND HISTOGRAMS OF ORIENTATIONS AND LENGTHS OF RIDGES AND DEPRESSIONS.

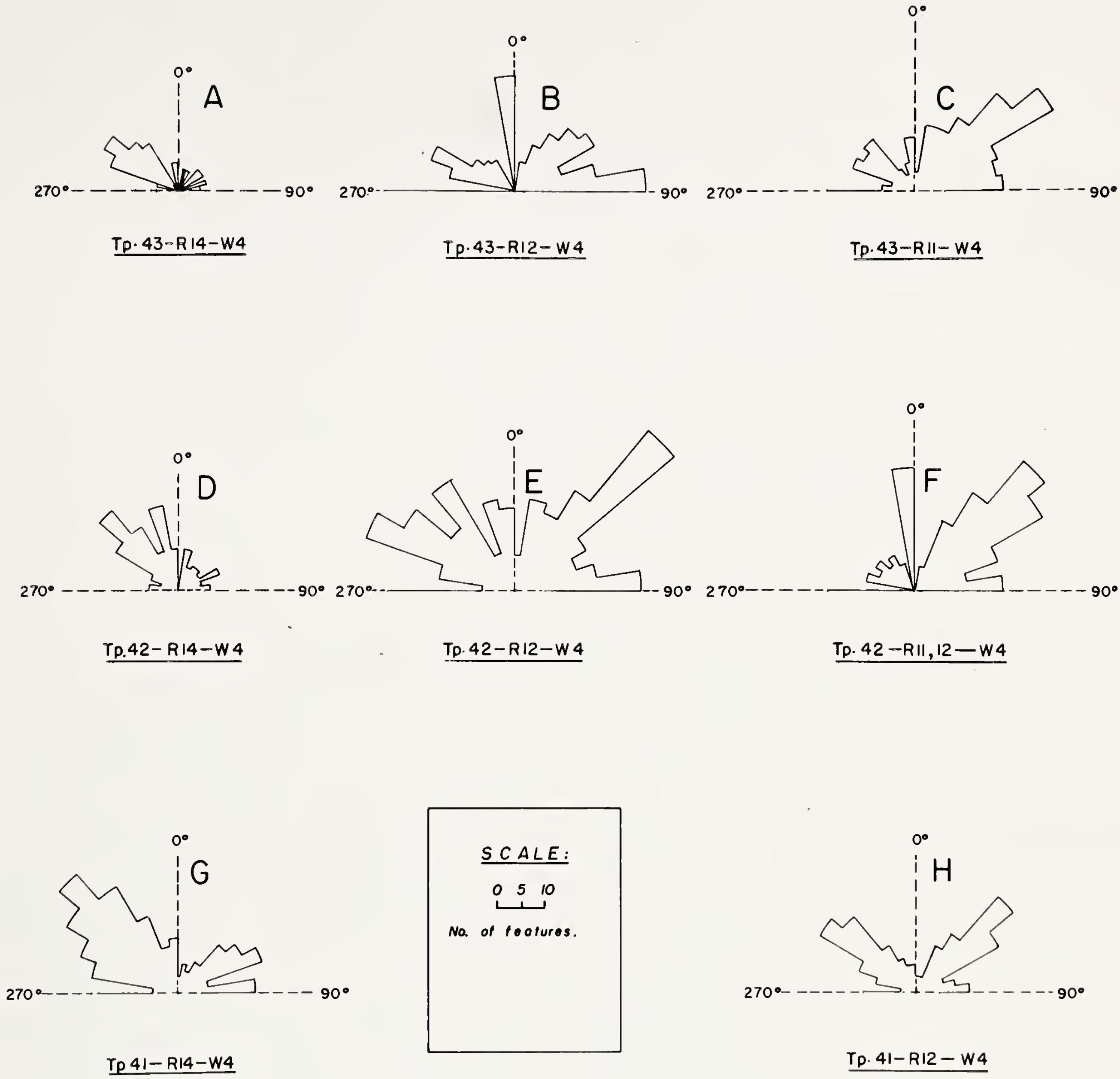


FIGURE 8· ROSE DIAGRAMS OF ORIENTATIONS OF DEPRESSIONS IN EAST-CENTRAL ALBERTA
(COURTESY OF THE RESEARCH COUNCIL OF ALBERTA.)

4. Significance of the frequency of occurrence and of the outlines in plan of depressions

The frequency of occurrence of depressions and their outlines in plan may be useful criteria for determining the concentration of ablation moraine within a locality. A clean ice surface melts down more uniformly than does one partially covered with debris, thus clean ice would not so readily tend to separate into ice blocks as would an ice mass partially covered with debris. Consequently, fewer and less pronounced depressions on a till surface may be considered indicative of former clean-ice areas and the surface features present were probably formed subglacially.

Depressions irregular or rectangular in plan may be more common in areas where the ice surface carried abundant superglacial debris and differential melting caused the formation of constructional depressions on final disappearance of the ice. Depressions circular or oval in plan may be more common in areas where ablation debris was relatively thin, scattered or absent, since one would expect ice blocks to develop rounded outlines as they wasted and thus impart similar outlines to the till surface.

5. Other significant data

Prairie mounds in the Carpio area (Plate VA; Fig. 4E) lie adjacent to, within, across and at the heads of meltwater channels. They are marked by one or more surface depressions. The close association of these features with meltwater channels suggests that some of these forms may have been formed at the bottom of moulins by ablation moraine sliding into the openings. Subsequently some of this material may have been reworked by meltwater, since features of this type often

contain stratified inclusions (Gravenor, 1955, p. 475) or have their central areas partly or completely filled with water deposited sediment (Stalker, 1960, p. 11). Gravenor (ibid.) suggests that similar features in western Canada originated as debris-filled pits on a stagnant-ice surface; melting of the ice left the pit fillings as mounds nearly circular in plan and in most cases marked by a single depression well above the level of the outer mound surface. That the prairie mounds in this area are ablation features is suggested by the occurrence of a shallow linear depression across the outer edge of one mound; this depression is believed to reflect the trend of a meltwater channel upon which it appears to be superimposed. Both of the above-mentioned variations in origin by ablation may be involved, as prairie mounds are not necessarily associated with meltwater channels.

Several prairie mounds in the St. Ann area (Plate XA; Fig. 6E) lack the roughly circular outlines of the similar features in the Carpio area; one of the features in the St. Ann area is 'link-shaped' in plan; the other is 'heart-shaped'. Their surfaces have a smooth, moulded appearance and distinct outer rims mark the upper surfaces. U-shaped cuts across the outer rims appear in several places and end abruptly at the outer 25-degree slopes common to these mounds. The cuts, supposedly formed by meltwater, must have been eroded by streams superimposed upon subglacially formed prairie mounds. Similar forms in central Alberta are labelled 'plains plateaux' by Stalker (1960, p. 9-11) who considers them to be 'ice-pressed drift forms'.

Several crevasse fillings illustrated in the upper part of Plate IIA, appear to be superimposed upon a closed disintegration ridge of subglacial origin. One crevasse filling lies along the crest of the closed ridge; another lies across part of the closed ridge and extends for a short distance across the flat central area enclosed by the ridge. This association of features again suggests that formation of some features by ablation and of others by squeezing-up may have been operative within a locality.

B. Features common to till surfaces of different ages

The small area of Illinoian drift studied in Decatur County, Illinois, exhibits no positive features (probably the result of post-glacial erosion). There are therfore no apparent positive features common to till surfaces of the different ages considered. Well-developed dendritic drainage is evident on the Illinoian till surface.

CONCLUSIONS

These till surfaces, currently labelled 'ground moraine', have surface features strongly suggestive of an origin either by formation under active glacier ice or by formation under generally stagnant ice conditions. Since the features are readily detected on air photos it is possible in many areas to map the separate deposits by means of such photos. In some cases stagnant ice features exhibit characteristics indicative of formation by ablation or by the squeezing-up of basal debris, thus allowing for a secondary classification. Surface features in those areas formerly covered by stagnant ice also exhibit particular outlines in plan, and patterns, that warrant the inclusion of morphological considerations within a genetic classification.

The classification that follows, patterned on Chamberlain's (1894) outline, is proposed for till surfaces commonly labelled 'ground moraine'. It incorporates the concepts outlined above as well as the more precise terminology for ice-stagnation features introduced by Tarr (1909, p. 51), Hoppe (1952, p. 5), Gravenor and Kupsch (1959, p. 48-55) and a few modified terms suggested by the writer.

I. Deposits that accumulate at the bottom of active glaciers (ground moraine)
   A. Surfaces marked by subglacial aggregations of till
      1. Drumlins
      2. Aggregations not strictly drumlinoid in form, i.e. crag and tail, fluting etc.

II. Deposits formed by ablation or by the squeezing-up of basal debris into cavities and crevasses in a stagnant or near-stagnant ice mass (ice-disintegration moraine: may be qualified as of low, intermediate or of high relief)

- A. Hummocky disintegration moraine
  - 1. Hummocky ablation moraine
  - 2. Hummocky basal moraine
- B. Closed disintegration ridges
  - 1. Closed ablation ridges (some types of prairie mounds, rimmed kettles)
  - 2. Closed basal ridges (rim ridges, terrace ridges, some types of prairie mounds)
- C. Linear disintegration ridges
  - 1. Linear ablation ridges (crevasse fillings, former medial and lateral moraines)
  - 2. Linear basal ridges
- D. Washboard ridges

The study area in Ontario marked by drumlins is a till surface that is definitely ground moraine. Till surfaces studied in Alaska are probably ground moraine but this conclusion is open to question as the data are rather inadequate.

The till surfaces studies in central North America are considered to be ice-disintegration moraine of low to intermediate relief, with the exception of the two small patches of ground moraine marked by fluting in Alberta and Montana.

In the Moose Mountain area, Saskatchewan, the till surface appears to be hummocky ablation moraine with occasional patches of linear and closed ablation ridges. The frequency of occurrence of depressions (25 per sq. mi.), the fact that many of the depressions appear to be of a constructional nature, and that irregular outlines in plan are most common, point towards an abundance of ablation moraine. Fluting was not noted in the study area; only where a spillway cuts across the drift surface outside the area under study has fluting been mapped (Christiansen, 1955, map), suggesting that the fluting may have been exposed when water erosion removed the ablation moraine. In localities where meltwater channels are numerous, basal moraine may also be exposed as the channels form a network between depressions suggesting that the meltwater streams carried little load and eroded the basal till (Fig. 2D).

The till surface in the Tolley and Carpio areas, North Dakota, appears to be composed of closed ablation ridges, linear ablation ridges and hummocky ablation moraine, along with patches of the various types of basal moraine. The ablation moraine cover in these areas is probably lighter than in the Moose Mountain area as depressions circular to oval in plan are more common and the frequency of occurrence of depressions (15 per sq. mi.) is lower.

The broadly arcuate pattern of the washboard ridges in the Jamestown area, North Dakota, suggest that the till surface in this area formed in the vicinity of a fairly even ice margin and that deposits away from the washboard ridges may therefore have formed under relatively clean ice by squeezing-up. The low frequency of occurrence

of depressions (six per sq. mi.) and their oval shapes are also taken to indicate a lack of ablation moraine.

Little can be said concerning the study areas in Indiana and Illinois other than that they appear to be a form of ice-disintegration moraine.

Hummocky ablation moraine, closed ablation ridges and linear ablation ridges (former medial and lateral moraines) appear to be superimposed upon ground moraine in the West Butte area and most of the Kevin area in Montana. Fluting evident on the surface of large disintegration ridges in the Kevin area warrants classifying this till surface as ground moraine.

The till surface studied in the Sedgewick and Coronation areas, Alberta, appears to consist primarily of low to intermediate relief hummocky basal moraine and linear basal ridges. The average number of depressions per square mile (12 per sq. mi. and 4 per sq. mi.) in the Sedgewick and Coronation areas is believed to indicate that clean ice was common to this area. The study area lies within the Torlea Flats, a drift surface that may have formed as the result of ice stagnation in the area between two belts of high-relief hummocky disintegration moraine, 25 to 50 miles apart. The width of these flats and the fact that the ice margin in this area was fairly even (no lobate ridge patterns were noted and the boundary with high-relief deposits is fairly regular) also favors the concept that clean ice was the rule in areas well removed from the former ice margin.

Some prairie mounds noted in the St. Ann area are probably ablation forms, but most of the exposed surface in this area appears

to be hummocky basal moraine with the occasional closed or linear basal ridge.

It is concluded that stagnation appears to have been the mode of ice wastage prevalent in the continental interior. This concept is not new, as Erdtman and Lewis (1931, p. 55) considered it likely that "large remnants of ice remained in places over the country as dead ice for a prolonged period" in the Edmonton area. Brown (1933, p. 157) proposed that large stagnant ice masses were left in the deeper valleys of central Massachusetts, and Gravenor (1955, p. 475) and Christiansen (1956, p. 9) suggested that ice stagnation was the mode of ice wastage in parts of western Canada. Also, Leighton (1959, p. 43) described crevasse fillings in Illinois believed to have originated in a stagnant ice mass.

Ice wastage by 'normal recession' appears to have been predominant in the areas studied in Ontario and Alaska. Since ground moraine surfaces are considered to have formed primarily under conditions of normal recession it appears that this type of till deposit is relatively rare and the usage of the term 'ground moraine' should likewide be rare.

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APPENDIX A

Selected Glossary

ablation - The term ablation is applied to the combined processes by which a glacier wastes (Howell, 1957, p. 1).

ablation moraine - A term introduced by Tarr (1909, p. 51) to apply to ridges of debris formed on the ice surface of a bulb-shaped ice foot. Howell (1957, p. 1) defines it as, drift believed to have been deposited from a superglacial position through the melting of underlying stagnant or near-stagnant ice. The latter definition is used in this paper; englacial drift is also included since much of this debris must reach a superglacial position as differential melting proceeds.

basal moraine - An irregular drift surface formed by the squeezing-up of basal debris into cavities and crevasses under stagnant or near-stagnant ice. Linear ridges formed within such an area are termed 'basal ridges'. Closed ridges formed around depressions by the squeezing-up process are labelled 'rim ridges', or where they lie partly within a depression the term 'terrace ridges' is used; both terms were proposed by Hoppe (1952, p. 24) for features formed by this process within hummocky moraine regions in Sweden.

Closed disintegration ridge - A regular or irregular closed ridge formed during ice disintegration, that originated by ablation

or by the squeezing-up of basal till into cavities and crevasses in stagnant or near-stagnant ice. This term was proposed by Gravenor and Kupsch (1959, p. 53) to apply to closed ridges that resulted from stagnant ice that separated into individual dead ice blocks.

closed ridge - A descriptive term applied to ridges of drift which close to form circular, oval or irregular features such as the rims enclosing certain depressions, certain types of prairie mounds, or irregular ridges in plan whose ends join to form an irregular constructional depression (Gravenor and Kupsch, 1959, p. 53).

crevasse filling - A special type of linear disintegration ridge that is characterized by marked straightness and a crest that is, as a rule, level and unbroken. It is associated with other ridges in such a manner as to indicate that it originated in an open crevasse in the ice (Flint, 1928, p. 415; Kupsch, 1956, p. 1-5).

disintegration moraine - A general term applied to drift surfaces formed by ablation or by the squeezing-up of debris into cavities or crevasses in stagnant or near-stagnant ice, and marked by ice disintegration features such as hummocks, closed and linear disintegration ridges and depressions. Gravenor and Kupsch (1959, p. 50) use the term in a discussion of hummocky disintegration moraine.

fluting - "... groups of ridge-like and groove-like land forms combining to impart a fluted pattern to the surface" (Flint, 1957, p. 56).

high-relief deposits - Drift deposits that have a local relief greater than 25 feet (Gravenor and Kupsch, 1959, p. 49).

hummock - A more or less circular hillock marked by a fairly even surface and lacking the surface depressions common to similar forms called prairie mounds.

ice-disintegration - "... the process of breaking up into numerous small blocks which finally comes about in a stagnant and thus wasting glacier" (Gravenor and Kupsch, 1959, p. 48).

intermediate-relief deposits - Drift deposits that have a local relief from 10 to 25 feet (Gravenor and Kupsch, 1959, p. 49)

linear disintegration ridge - A ridge generally straight to arcuate in plan formed during ice disintegration, that originated by ablation or by the squeezing-up of basal debris into cavities and crevasses in stagnant or near-stagnant ice. This term was proposed by Gravenor and Kupsch (1959, p. 53) to apply to linear ridges that resulted from stagnant ice that separated into individual dead-ice blocks that originated during stagnation or near-stagnation of the ice.

low-relief deposit - Drift deposits that have local relief of less than 10 feet (Gravenor and Kupsch, 1959, p. 49).

meltwater channel - "... any channel that carried meltwater from a glacier either under the ice, or parallel to, or away from the margin" (Christiansen, 1956, p. 21).

mound - Any prominent more or less isolated hill (Howell, 1957, p. 192).

open depression - A depression that has a natural outlet for surface drainage.

prairie mound - Oval to circular mounds that have upper surfaces marked by one or more depressions, or a series of concentric ridges about a small depression or knoll. The depressions lie well above the level of the drift surface next to the mound. These features are a special type of closed disintegration ridge formed in the manner suggested for closed disintegration ridges. The term was introduced by Gravenor (1955, p. 475) who applied it to nearly circular ablation features that in most cases have a central depression well above the level of adjacent surfaces. Gravenor (1960, p. 11) suggests the term prairie mound be dropped and the term moraine knob or moraine hummock be used in its place; Stalker (1960, p. 11) applies the term 'plains plateaux' to similar forms. The term prairie mound is retained in this paper since the term is now commonly used and the introduction of more new terminology for identical features may lead to confused usage.

rimmed kettle - A term applied to the composite feature formed by the enclosure of one or more kettles by an ablation ridge. Christiansen (1956, p. 11-12) used the term to apply to kettles enclosed by a circular ridge composed of till or stratified drift.

washboard ridge - Discontinuous disintegration ridges of variable height and width that are characterized by light-toned, dappled surfaces on air photos and which outline clearly the parallel trends and lobate patterns formed by such ridges. These ridges appear to have formed in the vicinity of the terminal margins of glaciers by shear plane and other glacial phenomena. Similar or identical forms have been termed 'minor end moraines', 'minor recessional ridges' (Flint, 1947, p. 130), 'washboard moraines' (Mawdsley, 1936, p. 9; Elson, 1957, p. 1721) and 'swells and swales' by Gwynne (1942, p. 206).